IBM XL C/C++ Advanced Edition for Blue Gene, V9.0
IBM XL Fortran Advanced Edition for Blue Gene, V11.1

# Using the IBM XL Compilers for Blue Gene

SC23-8513-00

IBM XL C/C++ Advanced Edition for Blue Gene, V9.0
IBM XL Fortran Advanced Edition for Blue Gene, V11.1

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**Note!**
Before using this information and the product it supports, be sure to read the general information under "Notices" on page 51.

**First Edition**

This edition applies to
- IBM XL C/C++ Advanced Edition for Blue Gene/P, V9.0 (Program 5799-HJE)
- IBM XL C/C++ Advanced Edition for Blue Gene/L, V9.0 (Program 5799-HJH)
- IBM XL Fortran Advanced Edition for Blue Gene/P, V11.1 (Program 5799-HJF)
- IBM XL Fortran Advanced Edition for Blue Gene/L, V11.1 (Program 5799-HJG)

and to all subsequent releases and modifications until otherwise indicated in new editions. Make sure you are using the correct edition for the level of the product.

# Contents

# About this document

The IBM® XL family of optimizing compilers allows you to develop C, C++, and Fortran applications for the IBM Blue Gene/P™ and Blue Gene/L™ supercomputers, and comprises the following products:

- IBM XL C/C++ Advanced Edition for Blue Gene/P, V9.0
- IBM XL C/C++ Advanced Edition for Blue Gene/L, V9.0
- IBM XL Fortran Advanced Edition for Blue Gene/P, V11.1
- IBM XL Fortran Advanced Edition for Blue Gene/L, V11.1

This document discusses specific considerations for developing, compiling, and optimizing C/C++ and Fortran applications for the Blue Gene/P PowerPC® 450 and Blue Gene/L PowerPC 440 processor architectures and their Double Hummer floating-point unit.

## Who should read this document

This document is for anyone who is developing or cross-compiling applications for the Blue Gene® supercomputer family, is familiar with the Linux® operating system, and who has some previous C, C++, or Fortran programming experience. Users new to the XL compilers can use this document to find information on the capabilities and features unique to the Blue Gene version of the products.

## How to use this document

This document is an add-on to the documentation suites for the IBM XL C/C++ Advanced Edition for Linux, V9.0 and IBM XL Fortran Advanced Edition for Linux, V11.1 products. It covers only material that is specific to the Blue Gene implementation of the compilers, but does not discuss information that is common to other Linux distributions.

## How this document is organized

This document includes the following topics:

- Chapter 1, “Compiling and linking applications for Blue Gene” describes the commands to cross-compile applications for Blue Gene, the Blue Gene compiler option defaults, Blue Gene specific compiler options, and unsupported compiler options.
- Chapter 2, “Tuning your code for Blue Gene” describes optimization strategies that best exploit the SIMD capabilities of the Blue Gene/P 450d and Blue Gene/L 440d processors. Topics include relevant optimization options, structuring data in adjacent pairs, inlining functions, aliasing, structuring computations, and checking for data alignment.
- Chapter 3, “Using the high performance libraries” describes the Mathematical Acceleration Subsystem (MASS) libraries of tuned scalar and vector functions available for Blue Gene.
- Chapter 4, “Using XL builtin floating-point functions for Blue Gene” summarizes the built-in functions that are specifically optimized for the 450d and 440d processors' Double Hummer dual FPU.

# Conventions used in this document

### Typographical conventions

The following table explains the typographical conventions used in this document.

*Table 1. Typographical conventions*

| Typeface | Indicates | Example |
|---|---|---|
| **bold** | Commands, executable names, compiler options and pragma directives | If you specify **-O3**, the compiler assumes **-qhot=level=0**. To prevent all HOT optimizations with **-O3**, you must specify **-qnohot**. |
| *italics* | Parameters or variables whose actual names or values are to be supplied by the user. Italics are also used to introduce new terms | Make sure that you update the *size* parameter if you return more than the *size* requested. |
| `monospace` | Programming keywords and library functions, compiler built-in functions, examples of program code, command strings, or user-defined names | If one or two cases of a `switch` statement are typically executed much more frequently than other cases, break out those cases by handling them separately before the `switch` statement. |
| **UPPERCASE bold** | Fortran programming keywords, statements, directives, and intrinsic procedures | The **ASSERT** directive applies only to the **DO** loop immediately following the directive, and not to any nested **DO** loops. |
| **lowercase bold** | Fortran lowercase programming keywords and library functions, compiler intrinsic procedures, file and directory names, examples of program code, command strings, or user-defined names | If you specify **-O3**, the compiler assumes **-qhot=level=0**. To prevent all HOT optimizations with **-O3**, you must specify **-qnohot**. |

### Syntax diagrams

Throughout this document, diagrams illustrate XL C/C++ or XL Fortran syntax. This section will help you to interpret and use those diagrams.

- Read the syntax diagrams from left to right, from top to bottom, following the path of the line.

  The ▸▸── symbol indicates the beginning of a command, directive, or statement.

  The ──▸ symbol indicates that the command, directive, or statement syntax is continued on the next line.

  The ▸── symbol indicates that a command, directive, or statement is continued from the previous line.

  The ──▸◂ symbol indicates the end of a command, directive, or statement.

  Fragments, which are diagrams of syntactical units other than complete commands, directives, or statements, start with the │── symbol and end with the ──│ symbol.

  IBM XL Fortran extensions are marked by a number in the syntax diagram with an explanatory note immediately following the diagram. Program units, procedures, constructs, interface blocks and derived-type definitions consist of

several individual statements. For such items, a box encloses the syntax representation, and individual syntax diagrams show the required order for the equivalent Fortran statements.

- Required items are shown on the horizontal line (the main path):


- Optional items are shown below the main path:


- If you can choose from two or more items, they are shown vertically, in a stack.

  If you *must* choose one of the items, one item of the stack is shown on the main path.


  If choosing one of the items is optional, the entire stack is shown below the main path.

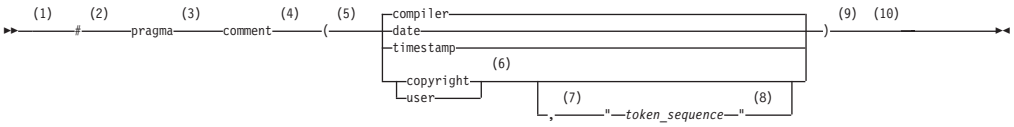

- An arrow returning to the left above the main line (a repeat arrow) indicates that you can make more than one choice from the stacked items or repeat an item. The separator character, if it is other than a blank, is also indicated:


- The item that is the default is shown above the main path.


- Keywords are shown in nonitalic letters and should be entered exactly as shown.
- Variables are shown in italicized lowercase letters. They represent user-supplied names or values.
- If punctuation marks, parentheses, arithmetic operators, or other such symbols are shown, you must enter them as part of the syntax.

**Sample syntax diagrams**

The following syntax diagram example shows the syntax for the **#pragma comment** directive.




**Notes:**

1 This is the start of the syntax diagram.

2 The symbol # must appear first.

3 The keyword `pragma` must appear following the # symbol.

4 The name of the pragma `comment` must appear following the keyword `pragma`.

5 An opening parenthesis must be present.

6 The comment type must be entered only as one of the types indicated: `compiler`, `date`, `timestamp`, `copyright`, or `user`.

7 A comma must appear between the comment type `copyright` or `user`, and an optional character string.

8 A character string must follow the comma. The character string must be enclosed in double quotation marks.

9 A closing parenthesis is required.

10 This is the end of the syntax diagram.

The following examples of the **#pragma comment** directive are syntactically correct according to the diagram shown above:

```
#pragma
comment(date)
#pragma comment(user)
#pragma comment(copyright,"This text will appear in the module")
```

### How to read syntax statements

Syntax statements are read from left to right:
- Individual required arguments are shown with no special notation.
- When you must make a choice between a set of alternatives, they are enclosed by { and } symbols.
- Optional arguments are enclosed by [ and ] symbols.
- When you can select from a group of choices, they are separated by | characters.
- Arguments that you can repeat are followed by ellipses (...).

### Example of a syntax statement

`EXAMPLE` *`char_constant`* `{`*`a`*`|`*`b`*`}[`*`c`*`|`*`d`*`]`*`e`*`[,`*`e`*`]... `*`name_list`*`{`*`name_list`*`}...`

The following list explains the syntax statement:
- Enter the keyword EXAMPLE.
- Enter a value for *char_constant*.
- Enter a value for *a* or *b*, but not for both.
- Optionally, enter a value for *c* or *d*.
- Enter at least one value for *e*. If you enter more than one value, you must put a comma between each.
- Optionally, enter the value of at least one *name* for *name_list*. If you enter more than one value, you must put a comma between each *name*.

**Note:** The same example is used in both the syntax-statement and syntax-diagram representations.

**Examples**

The examples in this document, except where otherwise noted, are coded in a simple style that does not try to conserve storage, check for errors, achieve fast performance, or demonstrate all possible methods to achieve a specific result.

**Notes on path names**

The path names shown in this document assume the default installation path for the XL C/C++ or XL Fortran compiler. By default, the compiler will be installed in the following directory on the selected disk:

**XL C/C++** `/opt/ibmcmp/vacpp/bg/9.0/`

**XL Fortran** `/opt/ibmcmp/xlf/bg/11.1/`

You can select a different destination (*relocation-path*) for the compiler. If you choose a different path, the compiler will be installed in the following directory:

**XL C/C++** *relocation-path*`/opt/ibmcmp/vacpp/bg/9.0/`

**XL Fortran** *relocation-path*`/opt/ibmcmp/xlf/bg/11.1/`

## Related information

**IBM XL C/C++ and XL Fortran documentation**

Product documentation is provided in the following formats:

- README files

  README files contain late-breaking information, including changes and corrections to the product documentation. README files are located in the root directory of the installation CD and by default in the following directory:

  **XL C/C++** `/opt/ibmcmp/vacpp/bg/9.0/`

  **XL Fortran** `/opt/ibmcmp/xlf/bg/11.1/`

- Installable man pages

  Man pages are provided for the compiler invocations and all command-line utilities provided with the product. Instructions for installing and accessing the man pages are provided in the *XL C/C++ Advanced Edition for Blue Gene, V9.0 Installation Guide* and *XL Fortran Advanced Edition for Blue Gene, V11.1 Installation Guide*.

- Information center

  The information center of searchable HTML files is viewable on the Web at http://publib.boulder.ibm.com/infocenter/compbgpl/v9v111/index.jsp.

- PDF documents

  PDF documents are located by default in the following directory:

  **XL C/C++** `/opt/ibmcmp/vacpp/bg/9.0/doc/en_US/pdf`

  **XL Fortran** `/opt/ibmcmp/xlf/bg/11.1/doc/en_US/pdf`

  These are also available on the Web at:

```
http://www.ibm.com/software/awdtools/xlcpp/library

and

http://www.ibm.com/software/awdtools/fortran/xlfortran/library
```

In addition to this document, the following documents comprise the full set of PDF files shipped with this product. The IBM XL C/C++ Advanced Edition for Linux, V9.0 and IBM XL Fortran Advanced Edition for Linux, V11.1 PDF files are included as additional references to complement the topics not covered in the Blue Gene specific documents.

*Table 2. PDF files shipped with IBM XL C/C++ Advanced Edition for Blue Gene/L, V9.0*

| Document title | PDF file name | Description |
|---|---|---|
| *IBM XL C/C++ Advanced Edition for Blue Gene, V9.0 Installation Guide*, GC23-8514-00 | install.pdf | Contains information for installing XL C/C++ for Blue Gene and configuring your environment for basic compilation and program execution. |
| *IBM XL C/C++ Advanced Edition for Linux, V9.0 Getting Started with XL C/C++*, SC23-5891-00 | getstart.pdf | Contains an introduction to theXL C/C++ for Linux product, with information on setting up and configuring your environment, compiling and linking programs, and troubleshooting compilation errors. |
| *IBM XL C/C++ Advanced Edition for Linux, V9.0 Compiler Reference*, SC23-5889-00 | compiler.pdf | Contains information about the various compiler options, pragmas, macros, environment variables, and built-in functions, including those used for parallel processing. |
| *IBM XL C/C++ Advanced Edition for Linux, V9.0 Language Reference*, SC23-5894-00 | language.pdf | Contains information about the C and C++ programming languages, as supported by IBM, including language extensions for portability and conformance to non-proprietary standards. |
| *IBM XL C/C++ Advanced Edition for Linux, V9.0 Programming Guide*, SC23-5890-00 | proguide.pdf | Contains information on advanced programming topics, such as application porting, interlanguage calls with Fortran code, library development, application optimization and parallelization, and the XL C/C++ for Linux high-performance libraries. |

*Table 3. PDF files shipped with IBM XL Fortran Advanced Edition for Blue Gene/L, V11.1*

| Document title | PDF file name | Description |
|---|---|---|
| *IBM XL Fortran Advanced Edition for Blue Gene, V11.1 Installation Guide*, GC23-8515-00 | install.pdf | Contains information for installing XL Fortran for Blue Gene and configuring your environment for basic compilation and program execution. |
| *IBM XL Fortran Advanced Edition for Linux, V11.1 Getting Started with XL Fortran*, SC23-5897-00 | getstart.pdf | Contains an introduction to the XL Fortran for Linux product, with information on setting up and configuring your environment, compiling and linking programs, and troubleshooting compilation errors. |
| *IBM XL Fortran Advanced Edition for Linux, V11.1 Compiler Reference*, SC23-5895-00 | cr.pdf | Contains information about the various compiler options and environment variables. |

*Table 3. PDF files shipped with IBM XL Fortran Advanced Edition for Blue Gene/L, V11.1 (continued)*

| Document title | PDF file name | Description |
|---|---|---|
| *IBM XL Fortran Advanced Edition for Linux, V11.1 Language Reference*, SC23-5894-00 | lr.pdf | Contains information about the Fortran programming language as supported by IBM, including language extensions for portability and conformance to non-proprietary standards, compiler directives and intrinsic procedures. |
| *IBM XL Fortran Advanced Edition for Linux, V11.1 Optimization and Programming Guide*, SC23-5898-00 | opg.pdf | Contains information on advanced programming topics, such as application porting, interlanguage calls, floating-point operations, input/output, application optimization and parallelization, and the XL Fortran high-performance libraries. |

More documentation related to the compilers, including red books, white papers, tutorials, and other articles, is available on the Web at:

`http://www.ibm.com/software/awdtools/xlcpp/library`

and

`http://www.ibm.com/software/awdtools/fortran/xlfortran/library`

### Other IBM publications

The following publications are available from the IBM Redbooks® site at URL http://www.redbooks.ibm.com:

- *Unfolding the IBM eServer™ Blue Gene Solution*, SG24-6686
- *Blue Gene/L: Application Development*, SG24-7179

You can search for, view, or download Redbooks, Redpapers, Hints and Tips, draft publications, and additional materials from this site.

Blue Gene literature, such as white papers, is also available at http://www.ibm.com/servers/deepcomputing/bluegene_literature.html

## Technical support

Additional technical support is available from the XL C/C++ or XL Fortran Support page. This page provides a portal with search capabilities to a selection of Technotes (technical notes) and other support documents. You can find the Support page on the Web at:

`http://www.ibm.com/software/awdtools/xlcpp/support`

or

`http://www.ibm.com/software/awdtools/fortran/xlfortran/support`

For the latest information about XL C/C++ or XL Fortran, visit the product information site at:

`http://www.ibm.com/software/awdtools/xlcpp`

or

http://www.ibm.com/software/awdtools/fortran/xlfortran

## How to send your comments

Your feedback is important in helping to provide accurate and high-quality information. If you have any comments about this document or any other XL C/C++ or XL Fortran documentation, send your comments by e-mail to:

compinfo@ca.ibm.com

Be sure to include the name of the document, the part number of the document, the version of the product, and, if applicable, the specific location of the text you are commenting on (for example, a page number or table number).

# Chapter 1. Compiling and linking applications for Blue Gene

This section contains information about compiling and linking applications that will run on a Blue Gene/P or Blue Gene/L supercomputer.

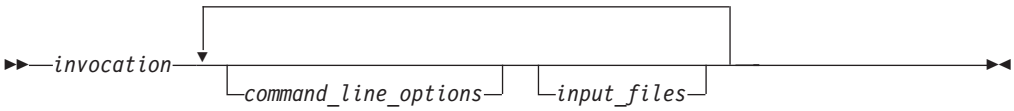
For complete information about compiler and linker options, refer to the following, additional documents:

- *XL C/C++ Advanced Edition for Linux, V9.0 Getting Started with XL C/C++*
- *XL C/C++ Advanced Edition for Linux, V9.0 Compiler Reference*
- *XL Fortran Advanced Edition for Linux, V11.1 Getting Started with XL Fortran*
- *XL Fortran Advanced Edition for Linux, V11.1 Compiler Reference*

## Compiling programs

To compile a source program, use any of the available XL C/C++ or XL Fortran for Blue Gene compiler invocation commands. The compiler commands prefixed with **blrts_** or **bg** on the SLES 9 platform are for cross-compiling applications for use on the Blue Gene/L computer. The **bg**-prefixed and **bg*_r** commands on the SLES 10 platform are for cross-compiling applications for use on the Blue Gene/P computer. The compiler invocations that are **not** prefixed with **blrts_** or **bg** create executables targeted for the SLES 10 platform, and are provided only for testing and debugging purposes. For the development of applications targeted for the SLES 10 platform, IBM provides the IBM XL C/C++ Advanced Edition for Linux, V9.0 and IBM XL Fortran Advanced Edition for Linux, V11.1 products. As well, only the compiler options which are supported by the **blrts_** or **bg** cross-compiler commands are supported when using these compiler invocations to create executables for the Blue Gene platform.

These commands use the following syntax, where *invocation* can be replaced with any valid compiler invocation command:




The parameters of the compiler invocation command can be the names of input files, compiler options, and linkage-editor options. These commands accept essentially the same XL C/C++ or XL Fortran language but use different default options. Read the appropriate **vac.cfg** or **xlf.cfg** configuration file to see which option defaults are used:

| Compiler | Configuration file |
|---|---|
| **XL C/C++** | `/etc/opt/ibmcmp/vac/bg/9.0/vac.cfg` |
| **XL Fortran** | `/etc/opt/ibmcmp/xlf/bg/11.1/xlf.cfg` |

Different forms of the XL compiler invocation commands support various levels of the C, C++, and Fortran languages. These compiler invocation commands are summarized in Table 4 on page 2, Table 5 on page 3, Table 6 on page 3, and Table 7 on page 4.

**Note:** For Blue Gene/P commands, the **_r**-suffixed invocations allow for threadsafe compilation and you can use them to link the programs that use

multithreading. Use these commands if you want to create threaded applications. The **-qsmp** option must only be used together with threadsafe compiler invocation modes.

*Table 4. XL C/C++ cross-compiler invocations for Blue Gene/L*

| Invocation | Funtionality |
|---|---|
| blrts_xlC<br>bgxlC<br>blrts_xlc++<br>bgxlc++ | Source files are compiled as C++ language source code. If any of your source files are C++, you must use this invocation to link with the correct runtime libraries. Source files are compiled with **-qalias=ansi** set.<br>Files with **.c** suffixes, assuming you have not used the **-+** or **-qsourcetype** compiler option . |
| blrts_xlc<br>bgxlc | Invokes the compiler for C source files. The following compiler options are implied with this invocation:<br>• -qlanglvl=extc99<br>• -qalias=ansi<br>• -qcpluscmt<br>• -qkeyword=inline |
| blrts_cc<br>bgcc | Invokes the compiler for C source files. The following compiler options are implied with this invocation:<br>• -qlanglvl=extended<br>• -qnoro<br>• -qnoroconst |
| blrts_c99<br>bgc99 | Invokes the compiler for C source files, with support for ISO C99 language features. Full ISO C99 (ISO/IEC 9899:1999) conformance requires the presence of C99-compliant header files and runtime libraries. The following compiler options are implied with this invocation:<br>• -qlanglvl=stdc99<br>• -qalias=ansi<br>• -qstrict_induction<br>• -D_ANSI_C_SOURCE<br>• -D_ISOC99_SOURCE<br>• -D__STRICT_ANSI__ |
| blrts_c89<br>bgc89 | Invokes the compiler for C source files, with support for ISO C89 language features. The following options are implied with this invocation:<br>• -qalias=ansi<br>• -qstrict_induction<br>• -qnolonglong<br>• -D_ANSI_C_SOURCE<br>• -D__STRICT_ANSI__<br>Use this invocation for strict conformance to the ANSI standard (ISO/IEC 9899:1990). |
| | |

*Table 5. XL C/C++ cross-compiler invocations for Blue Gene/P*

| Invocation | Funtionality |
|---|---|
| bgxlC<br>bgxlC_r<br>bgxlc++<br>bgxlc++_r | Source files are compiled as C++ language source code. If any of your source files are C++, you must use this invocation to link with the correct runtime libraries. Source files are compiled with **-qalias=ansi** set.<br>Files with **.c** suffixes, assuming you have not used the **-+** or **-qsourcetype** compiler option . |
| bgxlc<br>bgxlc_r | Invokes the compiler for C source files. The following compiler options are implied with this invocation:<br>• -qlanglvl=stdc89<br>• -qalias=ansi<br>• -qcpluscmt<br>• -qkeyword=inline |
| bgcc<br>bgcc_r | Invokes the compiler for C source files. The following compiler options are implied with this invocation:<br>• -qlanglvl=extended<br>• -qnoro<br>• -qnoroconst |
| bgc99<br>bgc99_r | Invokes the compiler for C source files, with support for ISO C99 language features. Full ISO C99 (ISO/IEC 9899:1999) conformance requires the presence of C99-compliant header files and runtime libraries. The following compiler options are implied with this invocation:<br>• -qlanglvl=stdc99<br>• -qalias=ansi<br>• -qstrict_induction<br>• -D_ANSI_C_SOURCE<br>• -D_ISOC99_SOURCE<br>• -D__STRICT_ANSI__ |
| bgc89<br>bgc89_r | Invokes the compiler for C source files, with support for ISO C89 language features. The following options are implied with this invocation:<br>• -qalias=ansi<br>• -qstrict_induction<br>• -qnolonglong<br>• -D_ANSI_C_SOURCE<br>• -D__STRICT_ANSI__<br>Use this invocation for strict conformance to the ANSI standard (ISO/IEC 9899:1990). |
| | |

*Table 6. XL Fortran cross-compiler invocations for Blue Gene/L*

| Invocation | Funtionality |
|---|---|
| blrts_xlf<br>bgxlf<br>blrts_fort77<br>bgfort77<br>blrts_f77<br>bgf77 | Makes programs conform more closely to the FORTRAN 77 standard. |
| | |

*Table 6. XL Fortran cross-compiler invocations for Blue Gene/L (continued)*

| Invocation | Funtionality |
|---|---|
| blrts_xlf90<br>bgxlf90<br>blrts_f90<br>bgf90 | Makes programs conform more closely to the Fortran 90 standard.<br><br>For full conformance, compile with any of the following additional compiler options or suboptions:<br>`-qnodirective -qnoescape -qextname -qfloat=nomaf:nofold -qnoswapomp -qlanglvl=90std` |
| blrts_xlf95<br>bgxlf95<br>blrts_f95<br>bgf95 | Makes programs conform more closely to the Fortran 95 standard.<br><br>For full conformance, compile with any of the following additional compiler options or suboptions:<br>`-qnodirective -qnoescape -qextname -qfloat=nomaf:nofold -qnoswapomp -qlanglvl=95std` |
| blrts_xlf2003<br>bgxlf2003<br>blrts_f2003<br>bgf2003 | Makes programs conform more closely to the Fortran 2003 standard.<br><br>For full conformance, compile with the following additional compiler options or suboptions:<br>`-qlanglvl=2003std -qnodirective -qnoescape -qextname -qfloat=nomaf:rndsngl:nofold -qnoswapomp -qstrictieeemod` |
| | |

*Table 7. XL Fortran cross-compiler invocations for Blue Gene/P*

| Invocation | Funtionality |
|---|---|
| bgxlf<br>bgxlf_r<br>bgf77<br>bgfort77 | Makes programs conform more closely to the FORTRAN 77 standard. |
| bgxlf90<br>bgxlf90_r<br>bgf90 | Makes programs conform more closely to the Fortran 90 standard.<br><br>For full conformance, compile with any of the following additional compiler options or suboptions:<br>`-qnodirective -qnoescape -qextname -qfloat=nomaf:nofold -qnoswapomp -qlanglvl=90std` |
| bgxlf95<br>bgxlf95_r<br>bgf95 | Makes programs conform more closely to the Fortran 95 standard.<br><br>For full conformance, compile with any of the following additional compiler options or suboptions:<br>`-qnodirective -qnoescape -qextname -qfloat=nomaf:nofold -qnoswapomp -qlanglvl=95std` |
| bgxlf2003<br>bgxlf2003_r<br>bgf2003 | Makes programs conform more closely to the Fortran 2003 standard.<br><br>For full conformance, compile with the following additional compiler options or suboptions:<br>`-qlanglvl=2003std -qnodirective -qnoescape -qextname -qfloat=nomaf:rndsngl:nofold -qnoswapomp -qstrictieeemod` |
| | |

## Compiler option defaults for Blue Gene/L

Compilations most commonly occur on the Front End Node. The resulting program can run on Blue Gene/L system without manually copying the executable to the Service Node. See the "Running Applications" topic in section 5.1 of the *Blue Gene/L Application Development* document to learn how to run programs on Blue Gene/L.

The **blrts_*** compiler invocation commands, or their **bg*** equivalents, set certain default compiler options to maximize the use of the Blue Gene/L architecture.

### -qarch=[440 | 440d]

#### Arguments

Specifies which instructions the compiler can generate. Suboptions include:

**440**
Generates code for the single floating-point unit (FPU) only.

**440d**
Generates parallel instructions for the 440d Double Hummer dual FPU. This is the default. Note that if you encounter problems with code generation, try resetting this option to **-qarch=440**.

**Note:** Since the Double Hummer FPU does not generate exceptions, **-qnoflttrap** is enabled by default. If you specify both **-qflttrap** and **-qarch=440d**, the compiler ignores the **-qflttrap** setting. You must specify **-qarch=440** if you want to use **-qflttrap**.

### -qnoautoconfig

Prevents optimization levels **-O4** and **-O5** from resetting the **-qarch** setting to **auto**, thereby preserving the **-qarch** setting for the target architecture. This allows for cross-compilation to other architectures, such as Blue Gene.

### -qtune=440

Optimizes code for the 440 family of processors. This is the default for **-qarch=440** and **-qarch=440d**.

## Unsupported options for Blue Gene/L

The following compiler options are not supported by the Blue Gene/L hardware and should not be used:

**-qsmp** This option requires shared memory parallelism, which is not used by the Blue Gene/L.

**-qpdf, -qshowpdf**
The XL C/C++ and XL Fortran compilers do not fully support tuning optimizations through profile-directed feedback (PDF) for Blue Gene/L.

**options specifying 64-bit mode**
Blue Gene/L uses a 32-bit architecture. You cannot compile in 64-bit mode. **-q64**, **-qwarn64**, and all other options that apply to 64-bit mode are unsupported.

**-qaltivec (C/C++)**
The 440 processor does not support VMX instructions or vector data types.

**-qenablevmx**
The 440 processor does not support VMX instructions or vector data types.

**-qpic** This option controls the selection of TOC size for Position Independent Code. PIC code is used for shared/dynamic libraries, which are not supported on Blue Gene/L.

**-qmkshrobj (C/C++)**
This option creates a shared library object. Shared libraries are not supported on Blue Gene/L.

## Compiler option defaults for Blue Gene/P

Compilations most commonly occur on the Front End Node. The resulting program can run on the Blue Gene/P system without manually copying the executable to the Service Node.

The **bg*** and **bg*_r** compiler invocation commands set certain default compiler options to maximize the use of the Blue Gene/P architecture.

### -qarch=[450 | 450d]

#### Arguments

Specifies which instructions the compiler can generate. Suboptions include:

**450**
Generates code for the single floating-point unit (FPU) only. This option avoids SIMD instructions being generated.

**450d**
Generates parallel instructions for the 450d Double Hummer dual FPU. This is the default. Note that if you encounter problems with code generation, try resetting this option to **-qarch=450**.

**Note:** Since the Double Hummer FPU does not generate exceptions, **-qnoflttrap** is enabled by default. If you specify both **-qflttrap** and **-qarch=450d**, the compiler ignores the **-qflttrap** setting. You must specify **-qarch=450** if you want to use **-qflttrap**.

### -qnoautoconfig

Prevents optimization levels **-O4** and **-O5** from resetting the **-qarch** setting to **auto**, thereby preserving the **-qarch** setting for the target architecture. This allows for cross-compilation to other architectures, such as Blue Gene.

### -qstaticlink (C/C++)

Although shared libraries are supported on the Blue Gene/P platform, note that **-qstaticlink** and **-qstaticlink=libgcc** are enabled by default. To use shared libraries, you must set the **-qnostaticlink** or **-qnostaticlink=libgcc** option.

### -qtune=450

Optimizes code for the 450 family of processors. This is the default for **-qarch=450**, **-qarch=450d** , or when no **-qarch** or **-qtune** settings are specified and the **bg** prefixed commands are used..

## Unsupported options for Blue Gene/P

The following compiler options are not supported by the Blue Gene/P hardware and should not be used:

**-qpdf, -qshowpdf**
The XL C/C++ and XL Fortran compilers do not fully support tuning optimizations through profile-directed feedback (PDF) for Blue Gene/P.

**options specifying 64-bit mode**
Blue Gene/P uses a 32-bit architecture. You cannot compile in 64-bit mode. **-q64**, **-qwarn64**, and all other options that apply to 64-bit mode are unsupported.

**-qaltivec (C/C++)**
The 450 processor does not support VMX instructions or vector data types.

**-qenablevmx**
The 450 processor does not support VMX instructions or vector data types.

## Blue Gene-specific XL C/C++ predefined macros

Predefined macros can be used to conditionally compile code for specific compilers, specific versions of compilers, specific environments and/or specific language features.

This section lists the Blue Gene-specific XL C/C++ predefined macros for the following categories:

- "Macros related to the platform"
- "Macros related to architecture settings" on page 8

See the ***Compiler predefined macros*** section in the *XL C/C++ Advanced Edition for Linux, V9.0 Compiler Reference* for a list of other XL C/C++ predefined macros.

### Macros related to the platform

The following predefined macros are provided to facilitate porting applications between platforms. All platform-related predefined macros are unprotected and may be undefined or redefined without warning unless otherwise specified.

*Table 8. Platform-related predefined macros*

| Predefined macro name | Description | Predefined value | Predefined under the following conditions |
|---|---|---|---|
| __bg__ | Indicates that this is a Blue Gene platform. | 1 | Always predefined for all Blue Gene platforms. |
| __bgp__ | Indicates that the architecture is PowerPC 450. | 1 | Predefined when the architecture is PowerPC 450. |
| __blrts, __blrts__ | Indicates that the architecture is PowerPC 440. | 1 | Predefined when the architecture is PowerPC 440. |
| __THW_BLUEGENE__ | Indicates that the target architecture is Blue Gene. | 1 | Predefined when the target is Blue Gene. |
| __TOS_BGP__ | Indicates that the target architecture is PowerPC 450. | 1 | Predefined when the target is PowerPC 450. |
| __TOS_BLRTS__ | Indicates that the target architecture is PowerPC 440. | 1 | Predefined when the target is PowerPC 440. |

## Macros related to architecture settings

The following macros can be tested for target architecture settings. All of these macros are predefined to a value of 1 by a **-qarch** compiler option setting, or any other compiler option that implies that setting. If the **-qarch** suboption enabling the feature is not in effect, then the macro is not defined.

*Table 9.* **-qarch***-related macros*

| Macro name | Description | Predefined by the following -qarch suboptions |
|---|---|---|
| _ARCH_440 | Indicates that the application is targeted to run on a PowerPC 440 processor. | **440**, **440d**, **450d** |
| _ARCH_440D | Indicates that the application is targeted to run on a PowerPC 440 processor. | **440d**, **450d** |
| _ARCH_450 | Indicates that the application is targeted to run on a PowerPC 450 processor. | **450**, **450d** |
| _ARCH_450D | Indicates that the application is targeted to run on a PowerPC 450 processor. | **450d** |

# Inline assembly statements

This section lists the constraints that apply to the Blue Gene platform for the **asm** keyword. These constraints address the handling of floating point instructions mainly for complex arithmetic.

The Blue Gene platform provides two parallel arithmetic pipes, with each pipe having its own floating point register (FPR) files. The primary FPR file corresponds with that defined in the PowerPC architecture; each primary FPR has a corresponding secondary FPR that is also 64-bits wide. The imaginary portion of the complex number is often kept in the secondary FPR (FPRs) and the real portion is kept in the corresponding primary FPR (FPRp). Complex operands are typically accessed in pairs, one primary and one secondary.

The constraint syntax is as follows:

`XL:`*`parameter`*`: ... :`*`parameter`*

Multiple letter constraint followed by `:` and then the parameter letters.

The operand that has the constraint `XL` cannot have any other constraint except the parameter constraints, listed below. The `XL` constraint must be the only constraint for the operand. The parameters defined for the `XL` constraint must be used with the `XL:` prefix.

The following constraints apply as parameters to the `XL` constraint:

**RP** FPR register pair constraint for two operands.

When this constraint is specified on an operand, a pair of registers (FPRp, FPRs) will be allocated for this operand and the operand that follows it. The register pair constraint cannot be used as the last operand in the asm statement.

**XP** Cross FPR pair constraint for two operands.

This contraint is similar to the `RP` constraint, except that the register pair is allocated as (FPRs, FPRp).

**p** Primary FPR constraint for 32/64 bit floating point operand.

This is equivalent to the `f` constraint. A primary FPR is allocated for the operand.

**s** Secondary FPR constraint for 32/64 bit floating point operand.

A secondary FPR is allocated for the operand.

**CP** FPR pair constraint for operand of the complex types.

The operand must be of any valid 32- or 64-bit complex type. A register pair (FPRp, FPRs) is allocated for the complex operand, one to hold the real portion and the other to hold the imaginary portion.

**XCP** Cross FPR pair constraint for operand of the complex types.

This is similar to the `CP` constraint, except that the register pair is allocated as (FPRs, FPRp).

**C/C++ only:** The C99 complex data type is not supported on Blue Gene, by default. To turn on C99 complex data type support, specify the **-qlanglvl=gnu_complex** option.

For ***clobbers***, ***f0*** to ***f63*** correspond to the Blue Gene floating point registers.

See the ***-qasm*** option in the *XL C/C++ Advanced Edition for Linux, V9.0 Compiler Reference*, as well.

# Chapter 2. Tuning your code for Blue Gene

The following sections describe strategies that you can use to best exploit the single-instruction-multiple-data (SIMD) capabilities of the Blue Gene/L 440d or Blue Gene/P 450d processor and the XL compilers' advanced instruction scheduling and register allocation algorithms.

## Using the compiler optimization options

The **-O3** compiler option provides a high level of optimization and automatically sets other compiler options. For example, the **-qfloat=rsqrt** and **-qmaxmem=1** options are set by default with **-O3**, unless **-qstrict** is specified. Specifying **-O3** implies **-qhot=level=0**, unless you explicitly specify **-qhot** or **-qhot=level=1** option. **-O3** also sets **-qfloat=norngchk** by default, which turns off range checking on input arguments for software divide and inlined square-root operations.

The **-qhot=simd** option enables SIMD vectorization of loops, and is enabled by default if you use **-O4**, **-O5**, or **-qhot** .

The **-O5** option provides maximum optimization opportunities at both compile and link time. For maximum optimization at compile time only, the **-O3** option is recommended.

For more information on optimization options, see *Optimizing your applications* in the *XL C/C++ Advanced Edition for Linux, V9.0 Programming Guide* and *Optimizing XL compiler applications* in the *XL Fortran Advanced Edition for Linux, V11.1 Optimization and Programming Guide*.

## Structuring data in adjacent pairs

The Blue Gene/L 440d or Blue Gene/P 450d processor's dual FPU includes special instructions for parallel computations. The compiler tries to pair adjacent double-precision floating point values, to operate on them in parallel. Therefore, you can speed up computations by defining data objects that occupy adjacent memory blocks and are naturally aligned. These include arrays or structures of floating-point values and complex data types.

Whether you use an array, a structure, or a complex scalar, the compiler searches for sequential pairs of data for which it can generate parallel instructions. For example, the C code in Figure 1 on page 12 allows each pair of elements in a structure to be operated on in parallel.

```
struct quad {
   double a, b, c, d;
};

struct quad x, y, z;

void foo()
{
   z.a = x.a + y.a;
   z.b = x.b + y.b;  /* can load parallel (x.a,x.b), and (y.a, y.b),
                        do parallel add, and store parallel (z.a, z.b) */

   z.c = x.c + y.c;
   z.d = x.d + y.d;  /* can load parallel (x.c,x.d), and (y.c, y.d),
                        do parallel add, and store parallel (z.c, z.d) */
}
```

*Figure 1. Adjacent paired data*

The advantage of using complex types in arithmetic operations is that the compiler automatically uses parallel add, subtract, and multiply instructions when complex types appear as operands to addition, subtraction, and multiplication operators. Furthermore, the data that you provide does not actually need to represent complex numbers. In fact, both elements are represented internally as two real values. See Complex type manipulation functions for a description of the set of built-in functions available for Blue Gene. These functions are designed to efficiently manipulate complex-type data and include a function to convert non-complex data to complex types.

## Using vectorizable basic blocks

The compiler schedules instructions most efficiently within *extended basic blocks*. These are code sequences which can contain conditional branches but have no entry points other than the first instruction. Specifically, minimize the use of branching instructions for the following:

- Handling of special cases, such as the generation of not-a-number (NaN) values
- C/C++ error handling that sets a value for **errno**.

  To explicitly inform the compiler that none of your code will set **errno**, compile with the **-qignerrno** compiler option (automatically set with **-O3** ).
- C++ exception handlers

  To explicitly inform the compiler that none of your code will throw any exceptions, and therefore, that no exception-handling code needs to be generated, compile with the **-qnoeh** compiler option.

In addition, the optimal basic blocks remove dependencies between computations, so that the compiler sees each statement as entirely independent. You can construct a basic block as a series of independent statements or as a loop that repeatedly computes the same basic block with different arguments.

The use of pointers in C/C++ may cause false dependencies between computations if the compiler cannot prove that the references are disjoint, causing automatic SIMDization to fail. It is recommended that pointer usage is minimized or **#pragma disjoint** is used to assert that pointers are disjoint from one another.

If you specify the **-qhot=simd** option, along with a minimum optimization level of **-O2**, the compiler can then vectorize these loops by applying various

transformations, such as unrolling and software pipelining. See Removing possibilities for aliasing (C/C++), for additional strategies for removing data dependencies.

## Using inline functions

An inline function is expanded in any context in which it is called. This avoids the normal performance overhead associated with the branching for a function call, and it allows functions to be included in basic blocks. The XL C/C++ and Fortran compilers provide several options for inlining.

The following options instruct the compiler to automatically inline all functions it deems appropriate:

- XL C/C++:
  - **-O** through **-O5**
  - **-qipa**
- XL Fortran:
  - **-O4** or **-O5**
  - **-qipa**

The following options allow you to select or name functions to be inlined:

- XL C/C++:
  - **-qinline**
  - **-Q**
- XL Fortran:
  - **-Q**

In C/C++, you can also use the standard **inline** function specifier or the **__attribute__(always_inline)** extension in your code to mark a function for inlining.

**Important!:** Do not overuse inlining because there are limits on how much inlining will be done. Mark only the most important functions.

For more information about the various compiler options for controlling function inlining, see the *XL Fortran Optimization and Programming* and *XL C/C++ Programming Guide*. For information on the different variations of the **inline** keyword supported by XL C/ C++, as well as the inlining function attribute extensions, see the *XL C/C++ Language Reference* .

## Turning off range checking

Specifying **-qfloat=rngchk** enables range checking on input arguments for software divide and inlined square root operations. When **-qnostrict** or **-O3** or higher optimization level is in effect, **-qfloat=norngchk** is enabled by default. The compiler may generate software division code instead of hardware floating-point divide instructions, and inlined code for square root operations. This may improve performance where division and square root operations are performed repeatedly within a loop. Turning off range checking should be used with caution, as in some cases it may produce undesirable results.

See the **-qfloat=rngchk | norngchk** description in the *XL C/C++ Advanced Edition for Linux, V9.0 Compiler Reference* or *XL Fortran Advanced Edition for Linux, V11.1 Compiler Reference* for more information.

## Removing possibilities for aliasing (C/C++)

When you use pointers to access array data in C/C++, the compiler cannot assume that the memory accessed by pointers will not be altered by other pointers that refer to the same address. For example, if two pointer input parameters share memory, the instruction to store the second parameter can overwrite the memory read from the first load instruction. This means that, after a store for a pointer variable, any load from a pointer must be reloaded. Consider the following code example:

```
int i = *p;
*q = 0;
j = *p;
```

If `*q` aliases `*p`, then the value must be reloaded from memory. If `*q` does not alias `*p`, the old value that is already loaded into `i` can be used.

To avoid the overhead of reloading values from memory every time they are referenced in the code, and allow the compiler to simply manipulate values that are already resident in registers, there are several strategies you can use. One approach is to assign input array element values to local variables and perform computations only on the local variables, as shown in Figure 2.

```
#include <math.h>
void reciprocal_roots (const double* x, double* f)
{
      double x0 = x[0] ;
      double x1 = x[1] ;
      double r0 = 1.0/sqrt(x0) ;
      double r1 = 1.0/sqrt(x1) ;
      f[0] = r0 ;
      f[1] = r1 ;
}
```

*Figure 2. Array parameters assigned to local variables*

If you are certain that two references do not share the same memory address, another approach is to use the **#pragma disjoint** directive. This directive asserts that two identifiers do not share the same storage within the scope of their use. Specifically, you can use the pragma to inform the compiler that two pointer variables do not point to the same memory address. The directive in the following exampleFigure 3 indicates to the compiler that the pointers-to-arrays of double x and f do not share memory:

```
__inline void ten_reciprocal_roots (double* x, double* f)
{
#pragma disjoint (*x, *f)
int i;
    for (i=0; i < 10; i++)
  f[i]= 1.0 / sqrt (x[i]);
}
```

*Figure 3. The #pragma disjoint directive*

**Important!:** The correct functioning of this directive requires that the two pointers really be disjoint. If they are not, the compiled program will not run correctly.

## Structuring floating-point computations

Floating-point operations are pipelined in the PowerPC 440 or PowerPC 450 processor so that one floating-point calculation is performed per cycle, with a latency of multiple cycles. The compiler can organize array computations and loop unrolling so that the 440d or 450d dual floating-point unit (FPU) usage remains efficient. Manually unrolling code may hinder higher optimizations.

For example, with the 440d or 450d, at high optimization with range checking turned off (**-qfloat=norngchk**), the function in Figure 4 should perform ten parallel reciprocal roots in about five cycles more than a single reciprocal root. This is because the compiler will perform two reciprocal roots in parallel and then use the empty cycles to run four more parallel reciprocal roots.

```
__inline void ten_reciprocal_roots (double* x, double* f)
{
#pragma disjoint (*x, *f)
    int i;
    for (i=0; i < 10; i++)
 f[i]= 1.0 / sqrt (x[i]);
}
```

*Figure 4. A function to calculate reciprocal roots for arrays of ten elements*

The definition in Figure 5 shows wrapping of the inlined, optimized `ten_reciprocal_roots` function inside a function that allows you to pass in arrays of any number of elements. This function then passes the values in batches of ten to the `ten_reciprocal_roots` function, and calculates the remaining operations individually.

```
static void unaligned_reciprocal_roots (double* x, double* f, int n)
{
#pragma disjoint (*x, *f)
    while (n >= 10) {
 ten_reciprocal_roots (x, f);
 x += 10;
 f += 10;
    }
    /* remainder */
    while (n > 0) {
 *f = 1.0 / sqrt (*x);
 f++, x++;
    }
}
```

*Figure 5. A function to pass values in batches of ten*

## Checking for data alignment

The Blue Gene architecture allows for two double-precision values to be loaded in parallel in a single cycle, provided that the load address is aligned such that the values loaded do not cross a cache-line boundary (which is 32-bytes). If they cross this boundary, the hardware generates an alignment trap. This trap may cause the program to crash or result in a severe performance penalty to be fixed at run time by the kernel.

The compiler does not generate these parallel load and store instructions unless it is sure that it is safe to do so. For non-pointer local and global variables, the

compiler knows when this is safe. To allow the compiler to generate these parallel loads and stores for accesses through pointers, include code that tests for correct alignment and gives the compiler hints.

To test for alignment, first create one version of a function which asserts the alignment of an input variable at that point in the program flow. You can use the C/C++ **__alignx** builtin function or the Fortran **ALIGNX** function to inform the compiler that the incoming data is correctly aligned according to a specific byte boundary, so it can efficiently generate loads and stores.

The function takes two arguments. The first argument is an integer constant expressing the number of alignment bytes (must be a positive power of two). The second argument is the variable name, typically a pointer to a memory address.

The C/C++ prototype for the function is:

```
extern
#ifdef __cplusplus
"builtin"
#endif
void __alignx (int n, const void *addr)
```

Here *n* is the number of bytes. For example, `__align(16, y)` specifies that the address `y` is 16-byte aligned.

In Fortran, the built-in subroutine is **ALIGNX(K,M)** , where *K* is of type INTEGER(4), and *M* is a variable of any type. When *M* is an integer pointer, the argument refers to the address of the pointee.

Figure 6 asserts that the variables `x` and `f` are aligned along 16-byte boundaries.

```
#include <math.h>
__inline void aligned_ten_reciprocal_roots (double* x, double* f)
{
#pragma disjoint (*x, *f)
int i;
    __alignx (16, x);
    __alignx (16, f);
    for (i=0; i < 10; i++)
 f[i]= 1.0 / sqrt (x[i]);
}
```

*Figure 6. Use of the __alignx built-in function*

**Note:** The **__alignx** function does not perform any alignment. It merely informs the compiler that the variables are aligned as specified, at the point where the **__alignx** call is placed. If the variables are not aligned correctly, the program can end abruptly or run very slowly.

After you create a function to handle input variables that are correctly aligned, you can then create a function that tests for alignment and then calls the appropriate function to perform the calculations. The function in Figure 7 on page 17 checks to see whether the incoming values are correctly aligned. Then it calls the aligned (Figure 6) or unaligned (Figure 4 on page 15) version of the function according to the result.

```
void reciprocal_roots (double *x, double *f, int n)
{
    /* are both x & f 16 byte aligned? */
    if ( ((((int) x) | ((int) f)) & 0xf) == 0) /*    This could also be done as:
           if (((int) x % 16 == 0) && ((int) f % 16) == 0) */
 aligned_ten_reciprocal_roots (x, f, n);
 else
 ten_reciprocal_roots (x, f, n);
}
```

*Figure 7. A function to test for alignment*

The alignment test in Figure 7 provides an optimized method of testing for 16-byte alignment by performing a bit-wise OR on the two incoming addresses and testing whether the lowest four bits are 0 (that is, 16-byte aligned).

# Chapter 3. Using the high performance libraries

XL C/C++ and XL Fortran Advanced Edition for Blue Gene are shipped with a set of libraries for high-performance mathematical computing:

- The Mathematical Acceleration Subsystem (MASS) is a set of libraries of tuned mathematical intrinsic functions that provide improved performance over the corresponding standard system math library functions. MASS is described in "Using the Mathematical Acceleration Subsystem libraries (MASS) ."

**Note:** In this discussion, rather than repeating the phrase *XL C/C++ function(s) or XL Fortran routine(s)*, the term *function(s)* is used to denote a XL C/C++ function(s) or XL Fortran routine(s) as it applies within its respective contexts.

## Using the Mathematical Acceleration Subsystem libraries (MASS)

The MASS libraries consist of a library of scalar XL C/C++ functions or XL Fortran routines described in "Using the scalar library"; and a set of vector libraries tuned for specific architectures, described in "Using the vector libraries" on page 22. The functions contained in both scalar and vector libraries are automatically called at certain levels of optimization, but you can also call them explicitly in your programs. Note that the accuracy and exception handling might not be identical in MASS functions and system library functions.

"Compiling and linking a program with MASS" on page 29 describes how to compile and link a program that uses the MASS libraries, and how to selectively use the MASS scalar library functions in concert with the regular system library scalar functions.

### Using the scalar library

The MASS scalar library, `libmass.a`, contains an accelerated set of frequently used math intrinsic functions that provide improved performance over the corresponding standard system library functions. These functions are available when you compile programs with any of the following options:

- **XL C/C++**: **-qhot -qignerrno -qnostrict**
- **XL Fortran**: **-qhot -qnostrict**
- **-qhot -O3**
- **-O4**
- **-O5**

the compiler automatically uses the faster MASS functions for most math library functions. In fact, the compiler first tries to "vectorize" calls to math library functions by replacing them with the equivalent MASS vector functions; if it cannot do so, it uses the MASS scalar functions. When the compiler performs this automatic replacement of math library functions, it uses versions of the MASS functions contained in the system library `libxlopt.a`. You do not need to add any special calls to the MASS functions in your code, or to link to the `libxlopt` library.

If you are not using any of the optimization options listed above, and want to explicitly call the MASS scalar functions, you can do so as follows:

**For XL C/C++**

1. Provide the prototypes for the functions (except `anint`, `cosisin`, `dnint`, `sincos`, and `rsqrt`), by including `math.h` in your source files.
2. Provide the prototypes for `anint`, `cosisin`, `dnint`, `sincos`, and `rsqrt`, by including `mass.h` in your source files.
3. Link the MASS scalar library libmass.a with your application. For instructions, see "Compiling and linking a program with MASS" on page 29.

**For XL Fortran**

1. Link the MASS scalar library libmass.a with your application. For instructions, see "Compiling and linking a program with MASS" on page 29
2. All the MASS scalar routines, except those listed in 3 are recognized by XL Fortran as intrinsic functions, so no explicit interface block is needed. To provide an interface block for the functions listed in 3, include `mass.include` in your source file.
3. Include `mass.include` in your source file for the following functions:
   - `acosf`, `acosh`, `acoshf`, `asinf`, `asinh`, `asinhf`, `atan2f`, `atanf`, `atanh`, `atanhf`, `cbrt`, `cbrtf`, `copysign`, `copysignf`, `cosf`, `coshf`, `cosisin`, `erff`, `erfcf`, `expf`, `expm1`, `expm1f`, `hypot`, `hypotf`, `lgammaf`, `logf`, `log10f`, `log1p`, `log1pf`, `powf`, `rsqrt`, `sincos`, `sinf`, `sinhf`, `tanf`, and `tanhf`

The MASS scalar functions accept double-precision parameters and return a double-precision result, or accept single-precision parameters and return a single-precision result, except `sincos` which gives 2 double-precision results. They are summarized in Table 10.

*Table 10. MASS scalar functions*

| Double-precision function | Single-precision function | Description | Double-precision function prototype | Single-precision function prototype |
|---|---|---|---|---|
| acos | acosf | Returns the arccosine of `x` | double acos (double x); | float acosf (float x); |
| acosh | acoshf | Returns the hyperbolic arccosine of `x` | double acosh (double x); | float acoshf (float x); |
| | anint | Returns the rounded integer value of `x` | | float anint (float x); |
| asin | asinf | Returns the arcsine of `x` | double asin (double x); | float asinf (float x); |
| asinh | asinhf | Returns the hyperbolic arcsine of `x` | double asinh (double x); | float asinhf (float x); |
| atan2 | atan2f | Returns the arctangent of `x/y` | double atan2 (double x, double y); | float atan2f (float x, float y); |
| atan | atanf | Returns the arctangent of `x` | double atan (double x); | float atanf (float x); |
| atanh | atanhf | Returns the hyperbolic arctangent of `x` | double atanh (double x); | float atanhf (float x); |

*Table 10. MASS scalar functions (continued)*

| Double-precision function | Single-precision function | Description | Double-precision function prototype | Single-precision function prototype |
|---|---|---|---|---|
| cbrt | cbrtf | Returns the cube root of x | double cbrt (double x); | float cbrtf (float x); |
| copysign | copysignf | Returns x with the sign of y | double copysign (double x,double y); | float copysignf (float x); |
| cos | cosf | Returns the cosine of x | double cos (double x); | float cosf (float x); |
| cosh | coshf | Returns the hyperbolic cosine of x | double cosh (double x); | float coshf (float x); |
| cosisin | | Returns a complex number with the real part the cosine of x and the imaginary part the sine of x. | double_Complex cosisin (double); | |
| dnint | | Returns the nearest integer to x (as a double) | double dnint (double x); | |
| erf | erff | Returns the error function of x | double erf (double x); | float erff (float x); |
| erfc | erfcf | Returns the complementary error function of x | double erfc (double x); | float erfcf (float x); |
| exp | expf | Returns the exponential function of x | double exp (double x); | float expf (float x); |
| expm1 | expm1f | Returns (the exponential function of x) – 1 | double expm1 (double x); | float expm1f (float x); |
| hypot | hypotf | Returns the square root of $x^2 + y^2$ | double hypot (double x, double y); | float hypotf (float x, float y); |
| lgamma | lgammaf | Returns the natural logarithm of the absolute value of the Gamma function of x | double lgamma (double x); | float lgammaf (float x); |
| log | logf | Returns the natural logarithm of x | double log (double x); | float logf (float x); |
| log10 | log10f | Returns the base 10 logarithm of x | double log10 (double x); | float log10f (float x); |

*Table 10. MASS scalar functions (continued)*

| Double-precision function | Single-precision function | Description | Double-precision function prototype | Single-precision function prototype |
|---|---|---|---|---|
| log1p | log1pf | Returns the natural logarithm of (x + 1) | double log1p (double x); | float log1pf (float x); |
| pow | powf | Returns x raised to the power y | double pow (double x, double y); | float powf (float x); |
| XL Fortran version: x**y | | Returns x raised to the power y | N/A | |
| rsqrt | | Returns the reciprocal of the square root of x | double rsqrt (double x); | |
| sin | sinf | Returns the sine of x | double sin (double x); | float sinf (float x); |
| sincos | | Sets *s to the sine of x and *c to the cosine of x | void sincos (double x, double* s, double* c); | |
| sinh | sinhf | Returns the hyperbolic sine of x | double sinh (double x); | float sinhf (float x); |
| sqrt | | Returns the square root of x | double sqrt (double x); | |
| tan | tanf | Returns the tangent of x | double tan (double x); | float tanf (float x); |
| tanh | tanhf | Returns the hyperbolic tangent of x | double tanh (double x); | float tanhf (float x); |

The following example shows the XL Fortran interface declaration for the `rsqrt` scalar function:

```
interface

real*8 function rsqrt (%val(x))
  real*8 x      ! Returns the reciprocal of the square root of x.
end function rsqrt

end interface
```

**Notes:**

- The trigonometric functions (`sin`, `cos`, `tan`) return NaN (Not-a-Number) for large arguments (where the absolute value is greater than $2^{50}$pi).
- In some cases, the MASS functions are not as accurate as the `libm.a` library, and they might handle edge cases differently (`sqrt(Inf)`, for example).

## Using the vector libraries

When you compile programs with any of the following options:

- **XL C/C++**: **-qhot -qignerrno -qnostrict**

- **XL Fortran**: **-qhot -qnostrict**
- **-qhot -O3**
- **-O4**
- **-O5**

the compiler automatically attempts to vectorize calls to system math functions by calling the equivalent MASS vector functions (with the exceptions of functions `vatan2` (XL Fortran), `vsatan2` (XL Fortran), `vdnint`, `vdint`, `vsincos`, `vssincos`, `vcosisin`, `vscosisin`, `vqdrt`, `vsqdrt`, `vrqdrt`, `vsrqdrt`, `vpopcnt4`, and `vpopcnt8`). For automatic vectorization, the compiler uses versions of the MASS functions contained in the system library `libxlopt.a`. You do not need to add any special calls to the MASS functions in your code, or to link to the libxlopt library.

If you are not using any of the optimization options listed above, and want to explicitly call any of the MASS vector functions, you can do so by including the XL C/C++ header `massv.h` or XL Fortran `massv.include` file in your source files and linking your application with the appropriate vector library. (Information on linking is provided in "Compiling and linking a program with MASS" on page 29.)

The single-precision and double-precision floating-point functions contained in the vector libraries are summarized in Table 11 on page 24 and Table 12 on page 26. The integer functions contained in the vector libraries are summarized in Table 13 on page 28 and Table 14 on page 28. Note that in C and C++ applications, only call by reference is supported, even for scalar arguments.

With the exception of a few functions (described below), all of the floating-point functions in the vector libraries accept three parameters (XL C/C++) or arguments (XL Fortran):

- a double-precision (for double-precision functions) or single-precision (for single-precision functions) vector output parameter or argument
- a double-precision (for double-precision functions) or single-precision (for single-precision functions) vector input parameter or argument
- an integer vector-length parameter or argument

The functions are of the form

*function_name* (*y*,*x*,*n*)

where *y* is the target vector, *x* is the source vector, and *n* is the vector length. The parameters or *y* and *x* are assumed to be double-precision for functions with the prefix `v`, and single-precision for functions with the prefix `vs`. As examples, the following code:

*XL C/C++*

```
#include <massv.h>

double x[500], y[500];
int n;
n = 500;
...
vexp (y, x, &n);
```

XL Fortran

```
include 'massv.include'

real*8 x(500), y(500)
integer n
n = 500
...
call vexp (y, x, n)
```

outputs a vector *y* of length 500 whose elements are exp(x[i]), where i=0,...,499(XL C/C++) or exp(x(i)), where i=1,...,500 (XL Fortran).

The functions `vdiv`, `vsincos`, `vpow`, and `vatan2` (and their single-precision versions, `vsdiv`, `vssincos`, `vspow`, and `vsatan2`) take four parameters. The functions `vdiv`, `vpow`, and `vatan2` take the parameters (*z*,*x*,*y*,*n*). The function `vdiv` outputs a vector *z* whose elements are x[i]/y[i], where i=0,..,*n–1(XL C/C++) or x(i)/y(i), where i=1,...,n (XL Fortran). The function `vpow` outputs a vector *z* whose elements are $x[i]^{y[i]}$, where i=0,..,*n–1(XL C/C++) or $x(i)^{y(i)}$, where i=1,..,n (XL Fortran). The function `vatan2` outputs a vector *z* whose elements are atan(x[i]/y[i]), where i=0,..,*n–1(XL C/C++), or atan(x(i)/y(i)), where i=1,..,n (XL Fortran). The function `vsincos` takes the parameters (*y*,*z*,*x*,*n*), and outputs two vectors, *y* and *z*, whose elements are sin(x[i]) and cos(x[i])(XL C/C++), or sin(x(i)) and cos(x(i)) (XL Fortran), respectively.

In `vcosisin(y,x,n)` and `vscosisin(y,x,n)`, *x* is a vector of *n* elements and the function outputs a vector *y* of *n* `complex`(XL C/C++), or `complex*16` (XL Fortran) elements of the form (cos(x[i]),sin(x[i]))(cos(x(i)),sin(x(i))) (XL Fortran).

*Table 11. MASS floating-point vector functions (XL C/C++)*

| Double-precision function | Single-precision function | Description | Double-precision function prototype | Single-precision function prototype |
|---|---|---|---|---|
| vacos | vsacos | Sets `y[i]` to the arc cosine of `x[i]`, for i=0,..,*n–1 | void vacos (double y[], double x[], int *n); | void vsacos (float y[], float x[], int *n); |
| vacosh | vsacosh | Sets `y[i]` to the hyperbolic arc cosine of `x[i]`, for i=0,..,*n–1 | void vacosh (double y[], double x[], int *n); | void vsacosh (float y[], float x[], int *n); |
| vasin | vsasin | Sets `y[i]` to the arc sine of `x[i]`, for i=0,..,*n–1 | void vasin (double y[], double x[], int *n); | void vsasin (float y[], float x[], int *n); |
| vasinh | vsasinh | Sets `y[i]` to the hyperbolic arc sine of `x[i]`, for i=0,..,*n–1 | void vasinh (double y[], double x[], int *n); | void vsasinh (float y[], float x[], int *n); |
| vatan2 | vsatan2 | Sets `z[i]` to the arc tangent of `x[i]/y[i]`, for i=0,..,*n–1 | void vatan2 (double z[], double x[], double y[], int *n); | void vsatan2 (float z[], float x[], float y[], int *n); |
| vatanh | vsatanh | Sets `y[i]` to the hyperbolic arc tangent of `x[i]`, for i=0,..,*n–1 | void vatanh (double y[], double x[], int *n); | void vsatanh (float y[], float x[], int *n); |
| vcbrt | vscbrt | Sets `y[i]` to the cube root of `x[i]`, for i=0,..,*n-1 | void vcbrt (double y[], double x[], int *n); | void vscbrt (float y[], float x[], int *n); |
| vcos | vscos | Sets `y[i]` to the cosine of `x[i]`, for i=0,..,*n–1 | void vcos (double y[], double x[], int *n); | void vscos (float y[], float x[], int *n); |
| vcosh | vscosh | Sets `y[i]` to the hyperbolic cosine of `x[i]`, for i=0,..,*n–1 | void vcosh (double y[], double x[], int *n); | void vscosh (float y[], float x[], int *n); |

*Table 11. MASS floating-point vector functions (XL C/C++) (continued)*

| Double-precision function | Single-precision function | Description | Double-precision function prototype | Single-precision function prototype |
|---|---|---|---|---|
| vcosisin | vscosisin | Sets the real part of y[i] to the cosine of x[i] and the imaginary part of y[i] to the sine of x[i], for i=0,..,*n–1 | void vcosisin (double _Complex y[], double x[], int *n); | void vscosisin (float _Complex y[], float x[], int *n); |
| vdint | | Sets y[i] to the integer truncation of x[i], for i=0,..,*n–1 | void vdint (double y[], double x[], int *n); | |
| vdiv | vsdiv | Sets z[i] to x[i]/y[i], for i=0,..,*n–1 | void vdiv (double z[], double x[], double y[], int *n); | void vsdiv (float z[], float x[], float y[], int *n); |
| vdnint | | Sets y[i] to the nearest integer to x[i], for i=0,..,n–1 | void vdnint (double y[], double x[], int *n); | |
| vexp | vsexp | Sets y[i] to the exponential function of x[i], for i=0,..,*n–1 | void vexp (double y[], double x[], int *n); | void vsexp (float y[], float x[], int *n); |
| vexpm1 | vsexpm1 | Sets y[i] to (the exponential function of x[i])-1, for i=0,..,*n–1 | void vexpm1 (double y[], double x[], int *n); | void vsexpm1 (float y[], float x[], int *n); |
| vlog | vslog | Sets y[i] to the natural logarithm of x[i], for i=0,..,*n–1 | void vlog (double y[], double x[], int *n); | void vslog (float y[], float x[], int *n); |
| vlog10 | vslog10 | Sets y[i] to the base-10 logarithm of x[i], for i=0,..,*n–1 | void vlog10 (double y[], double x[], int *n); | void vslog10 (float y[], float x[], int *n); |
| vlog1p | vslog1p | Sets y[i] to the natural logarithm of (x[i]+1), for i=0,..,*n–1 | void vlog1p (double y[], double x[], int *n); | void vslog1p (float y[], float x[], int *n); |
| vpow | vspow | Sets z[i] to x[i] raised to the power y[i], for i=0,..,*n-1 | void vpow (double z[], double x[], double y[], int *n); | void vspow (float z[], float x[], float y[], int *n); |
| vqdrt | vsqdrt | Sets y[i] to the fourth root of x[i], for i=0,..,*n-1 | void vqdrt (double y[], double x[], int *n); | void vsqdrt (float y[], float x[], int *n); |
| vrcbrt | vsrcbrt | Sets y[i] to the reciprocal of the cube root of x[i], for i=0,..,*n-1 | void vrcbrt (double y[], double x[], int *n); | void vsrcbrt (float y[], float x[], int *n); |
| vrec | vsrec | Sets y[i] to the reciprocal of x[i], for i=0,..,*n–1 | void vrec (double y[], double x[], int *n); | void vsrec (float y[], float x[], int *n); |

*Table 11. MASS floating-point vector functions (XL C/C++) (continued)*

| Double-precision function | Single-precision function | Description | Double-precision function prototype | Single-precision function prototype |
|---|---|---|---|---|
| vrqdrt | vsrqdrt | Sets `y[i]` to the reciprocal of the fourth root of `x[i]`, for i=0,..,*n-1 | void vrqdrt (double y[], double x[], int *n); | void vsrqdrt (float y[], float x[], int *n); |
| vrsqrt | vsrsqrt | Sets `y[i]` to the reciprocal of the square root of `x[i]`, for i=0,..,*n–1 | void vrsqrt (double y[], double x[], int *n); | void vsrsqrt (float y[], float x[], int *n); |
| vsin | vssin | Sets `y[i]` to the sine of `x[i]`, for i=0,..,*n–1 | void vsin (double y[], double x[], int *n); | void vssin (float y[], float x[], int *n); |
| vsincos | vssincos | Sets `y[i]` to the sine of `x[i]` and `z[i]` to the cosine of `x[i]`, for i=0,..,*n–1 | void vsincos (double y[], double z[], double x[], int *n); | void vssincos (float y[], float z[], float x[], int *n); |
| vsinh | vssinh | Sets `y[i]` to the hyperbolic sine of `x[i]`, for i=0,..,*n–1 | void vsinh (double y[], double x[], int *n); | void vssinh (float y[], float x[], int *n); |
| vsqrt | vssqrt | Sets `y[i]` to the square root of `x[i]`, for i=0,..,*n–1 | void vsqrt (double y[], double x[], int *n); | void vssqrt (float y[], float x[], int *n); |
| vtan | vstan | Sets `y[i]` to the tangent of `x[i]`, for i=0,..,*n-1 | void vtan (double y[], double x[], int *n); | void vstan (float y[], float x[], int *n); |
| vtanh | vstanh | Sets `y[i]` to the hyperbolic tangent of `x[i]`, for i=0,..,*n–1 | void vtanh (double y[], double x[], int *n); | void vstanh (float y[], float x[], int *n); |

Table 12

*Table 12. MASS floating-point vector library functions (XL Fortran)*

| Double-precision function | Single-precision function | Arguments | Description |
|---|---|---|---|
| vacos | vsacos | `(y,x,n)` | Sets y(i) to the arc cosine of x(i), for i=1,..,n |
| vacosh | vsacosh | `(y,x,n)` | Sets y(i) to the hyperbolic arc cosine of x(i), for i=1,..,n |
| vasin | vsasin | `(y,x,n)` | Sets y(i) to the arc sine of x(i), for i=1,..,n |
| vasinh | vsasinh | `(y,x,n)` | Sets y(i) to the arc hyperbolic sine of x(i), for i=1,..,n |
| vatan2 | vsatan2 | `(z,x,y,n)` | Sets z(i) to the arc tangent of x(i)/y(i), for i=1,..,n |
| vatanh | vsatanh | `(y,x,n)` | Sets y(i) to the arc hyperbolic tangent of x(i), for i=1,..,n |

*Table 12. MASS floating-point vector library functions (XL Fortran) (continued)*

| Double-precision function | Single-precision function | Arguments | Description |
|---|---|---|---|
| vcbrt | vscbrt | (y,x,n) | Sets y(i) to the cube root of x(i), for i=1,..,n |
| vcos | vscos | (y,x,n) | Sets y(i) to the cosine of x(i), for i=1,..,n |
| vcosh | vscosh | (y,x,n) | Sets y(i) to the hyperbolic cosine of x(i), for i=1,..,n |
| vcosisin | vscosisin | (y,x,n) | Sets the real part of y(i) to the cosine of x(i) and the imaginary part of y(i) to the sine of x(i), for i=1,..,n |
| vdint | | (y,x,n) | Sets y(i) to the integer truncation of x(i), for i=1,..,n |
| vdiv | vsdiv | (z,x,y,n) | Sets z(i) to x(i)/y(i), for i=1,..,n |
| vdnint | | (y,x,n) | Sets y(i) to the nearest integer to x(i), for i=1,..,n |
| vexp | vsexp | (y,x,n) | Sets y(i) to the exponential function of x(i), for i=1,..,n |
| vexpm1 | vsexpm1 | (y,x,n) | Sets y(i) to (the exponential function of x(i))-1, for i=1,..,n |
| vlog | vslog | (y,x,n) | Sets y(i) to the natural logarithm of x(i), for i=1,..,n |
| vlog10 | vslog10 | (y,x,n) | Sets y(i) to the base-10 logarithm of x(i), for i=1,..,n |
| vlog1p | vslog1p | (y,x,n) | Sets y(i) to the natural logarithm of (x(i)+1), for i=1,..,n |
| vpow | vspow | (z,x,y,n) | Sets z(i) to x(i) raised to the power y(i), for i=1,..,n |
| vqdrt | vsqdrt | (y,x,n) | Sets y(i) to the 4th root of x(i), for i=1,..,n |
| vrcbrt | vsrcbrt | (y,x,n) | Sets y(i) to the reciprocal of the cube root of x(i), for i=1,..,n |
| vrec | vsrec | (y,x,n) | Sets y(i) to the reciprocal of x(i), for i=1,..,n |
| vrqdrt | vsrqdrt | (y,x,n) | Sets y(i) to the reciprocal of the 4th root of x(i), for i=1,..,n |
| vrsqrt | vsrsqrt | (y,x,n) | Sets y(i) to the reciprocal of the square root of x(i), for i=1,..,n |
| vsin | vssin | (y,x,n) | Sets y(i) to the sine of x(i), for i=1,..,n |
| vsincos | vssincos | (y,z,x,n) | Sets y(i) to the sine of x(i) and z(i) to the cosine of x(i), for i=1,..,n |
| vsinh | vssinh | (y,x,n) | Sets y(i) to the hyperbolic sine of x(i), for i=1,..,n |
| vsqrt | vssqrt | (y,x,n) | Sets y(i) to the square root of x(i), for i=1,..,n |

*Table 12. MASS floating-point vector library functions (XL Fortran) (continued)*

| Double-precision function | Single-precision function | Arguments | Description |
|---|---|---|---|
| vtan | vstan | (y,x,n) | Sets y(i) to the tangent of x(i), for i=1,..,n |
| vtanh | vstanh | (y,x,n) | Sets y(i) to the hyperbolic tangent of x(i), for i=1,..,n |

XL C/C++ Integer functions are of the form *function_name* (*x*[], **n*), where x[] is a vector of 4-byte (for vpopcnt4) or 8-byte (for vpopcnt8) numeric objects (integral or floating-point), and *n is the vector length.

*Table 13. MASS integer vector library functions (XL C/C++)*

| Function | Description | Prototype |
|---|---|---|
| vpopcnt4 | Returns the total number of 1 bits in the concatenation of the binary representation of x[i], for i=0,..,*n–1 , where x is a vector of 32-bit objects. | unsigned int vpopcnt4 (void *x, int *n) |
| vpopcnt8 | Returns the total number of 1 bits in the concatenation of the binary representation of x[i], for i=0,..,*n–1 , where x is a vector of 64-bit objects. | unsigned int vpopcnt8 (void *x, int *n) |

*Table 14. MASS integer vector library functions (XL Fortran)*

| Function | Description | Interface |
|---|---|---|
| vpopcnt4 | Returns the total number of 1 bits in the concatenation of the binary representation of x(i), for i=1,...,n, where x is vector of 32-bit objects | integer*4 function vpopcnt4 (x, n) integer*4 x(*), n |
| vpopcnt8 | Returns the total number of 1 bits in the concatenation of the binary representation of x(i), for i=1,...,n, where x is vector of 64-bit objects | integer*4 function vpopcnt8 (x, n) integer*8 x(*) integer*4 n |

The following example shows XL Fortran interface declarations for some of the MASS double-precision vector routines:

```
interface

subroutine vsqrt (y, x, n)
  real*8 y(*), x(*)
  integer n        ! Sets y(i) to the square root of x(i), for i=1,..,n
end subroutine vsqrt

subroutine vrsqrt (y, x, n)
  real*8 y(*), x(*)
  integer n        ! Sets y(i) to the reciprocal of the square root of x(i),
                   ! for i=1,..,n
end subroutine vrsqrt

end interface
```

The following example shows XL Fortran interface declarations for some of the MASS single-precision vector routines:

```
interface

subroutine vssqrt (y, x, n)
  real*4 y(*), x(*)
  integer n       ! Sets y(i) to the square root of x(i), for i=1,..,n
end subroutine vssqrt

subroutine vsrsqrt (y, x, n)
  real*4 y(*), x(*)
  integer n       ! Sets y(i) to the reciprocal of the square root of x(i),
                  ! for i=1,..,n
end subroutine vsrsqrt

end interface
```

### Overlap of input and output vectors

In most applications, the MASS vector functions are called with disjoint input and output vectors; that is, the two vectors do not overlap in memory. Another common usage scenario is to call them with the same vector for both input and output parameters for example, `vsin (y, y, &n)` (XL C/C++) or `vsin (y, y, n)` (XL Fortran). Other kinds of overlap (where input and output vectors are neither disjoint nor identical) should be avoided, since they may produce unexpected results:

- For calls to vector functions that take one input and one output vector (for example, `vsin (y, x, n)`):

  The vectors `x[0:n-1] and y[0:n-1]` (XL C/C++) or `x(1:n) and y(1:n)` (XL Fortran) must be either disjoint or identical, or unexpected results may be obtained.

- For calls to vector functions that take two input vectors, for example, `vatan2 (y, x1, x2, &n)` (XL C/C++) or `vatan2 (y, x1, x2, n)` (XL Fortran):

  The previous restriction applies to both pairs of vectors y,x1 and y,x2. That is, `y[0:n-1] and x1[0:n-1]` (XL C/C++) or `y(1:n) and x1(1:n)` (XL Fortran) must be either disjoint or identical; and `y[0:n-1] and x2[0:n-1]` (XL C/C++) or `y(1:n) and x2(1:n)` (XL Fortran) must be either disjoint or identical.

- For calls to vector functions that take two output vectors, for example, `vsincos (y1, y2, x, &n)` (XL C/C++) or `vsincos (y1, y2, x, n)` (XL Fortran):

  The above restriction applies to both pairs of vectors y1,x and y2,x. That is, `y1[0:n-1] and x[0:n-1]` (XL C/C++) or `y1(1:n) and x(1:n)` (XL Fortran) must be either disjoint or identical; and `y2[0:n-1] and x[0:n-1]` (XL C/C++) or `y2(1:n) and x(1:n)` (XL Fortran) must be either disjoint or identical. Also, the vectors `y1[0:n-1] and y2[0:n-1]` (XL C/C++) or `y1(1:n) and y2(1:n)` (XL Fortran) must be disjoint.

### Consistency of MASS vector functions

All the functions in the MASS vector libraries are consistent, in the sense that a given input value will always produce the same result, regardless of its position in the vector, and regardless of the vector length.

## Compiling and linking a program with MASS

To compile an application that calls the functions in the MASS libraries, specify **mass** and **massv** on the **-l** linker option.

For example, if the MASS libraries are installed in the default directory, you could specify one of the following:

```
bgxlc progc.c -o progc -lmass -lmassv

bgxlf progf.f -o progf -lmass -lmassv
```

The MASS functions must run in the default rounding mode and floating-point exception trapping settings.

## Using libmass.a with the math system library

If you wish to use the libmass.a scalar library for some functions and the normal math library libm.a for other functions, follow this procedure to compile and link your program:

1. Use the **ar** command to extract the object files of the desired functions from libmass.a. For most functions, the object file name is the function name followed by `.s32.o`.[1] For example, to extract the object file for the `tan` function, the command would be:

   ```
   ar -x tan.s32.o libmass.a
   ```

2. Archive the extracted object files into another library:

   ```
   ar -qv libfasttan.a tan.s32.o
   ranlib libfasttan.a
   ```

3. Create the final executable using **bgxlc** or **bgxlf**, specifying **-lfasttan** instead of **-lmass**:

   ```
   bgxlc sample.c -o sample dir_containing_libfasttan -lfasttan

   OR

   bgxlf sample.f -o sample -L dir_containing_libfasttan -lfasttan
   ```

   This links only the `tan` function from MASS (now in `libfasttan.a`) and the remainder of the math functions from the standard system library.

**Exceptions:**

1. The `sin` and `cos` functions are both contained in the object file sincos.s32.o. The `cosisin` and `sincos` functions are both contained in the object file cosisin.s32.o.

# Chapter 4. Using XL builtin floating-point functions for Blue Gene

The XL C/C++ and XL Fortran compilers include a set of built-in functions that are optimized for the PowerPC architecture. For a full description of them, refer to the following documents (available from the Web pages listed at the beginning of this chapter):

- *Built-in functions for POWER™ and PowerPC architectures* in *XL C/C++ Advanced Edition for Linux, V9.0 Compiler Reference*
- *Intrinsic procedures* in *XL Fortran Advanced Edition for Linux, V11.1 Language Reference*

In addition, on Blue Gene, the XL compilers provide a set of built-in functions that are specifically optimized for the PowerPC 440 or PowerPC 450 Double Hummer dual FPU. These built-in functions provide an almost one-to-one correspondence with the Double Hummer instruction set.

All of the C/C++ and Fortran built-in functions operate on complex data types, which have an underlying representation of a two-element array, in which the real part represents the *primary* element and the imaginary part represents the *second* element. The input data you provide does not actually need to represent complex numbers: in fact, both elements are represented internally as two real values, and none of the built-in functions actually performs complex arithmetic. A set of built-in functions especially designed to efficiently manipulate complex-type variables is also available.

The Blue Gene built-in functions perform the several types of operations as explained in the following paragraphs.

*Parallel* operations perform SIMD computations on the primary and secondary elements of one or more input operands. They store the results in the corresponding elements of the output. As an example, Figure 8 on page 32 illustrates how a parallel multiply operation is performed.

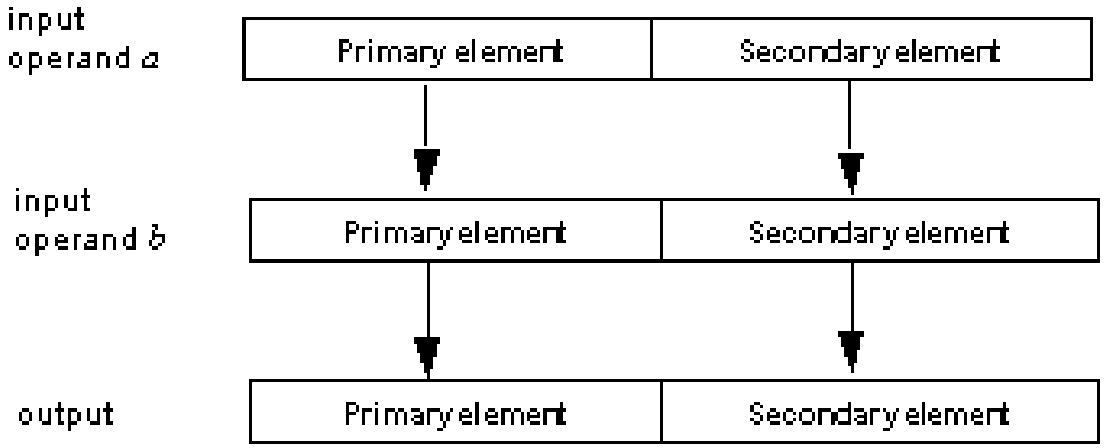



*Figure 8. Parallel operations*

*Cross* operations perform SIMD computations on the opposite primary and secondary elements of one or more input operands. They store the results in the corresponding elements in the output. As an example, Figure 9 illustrates how a cross-multiply operation is performed.

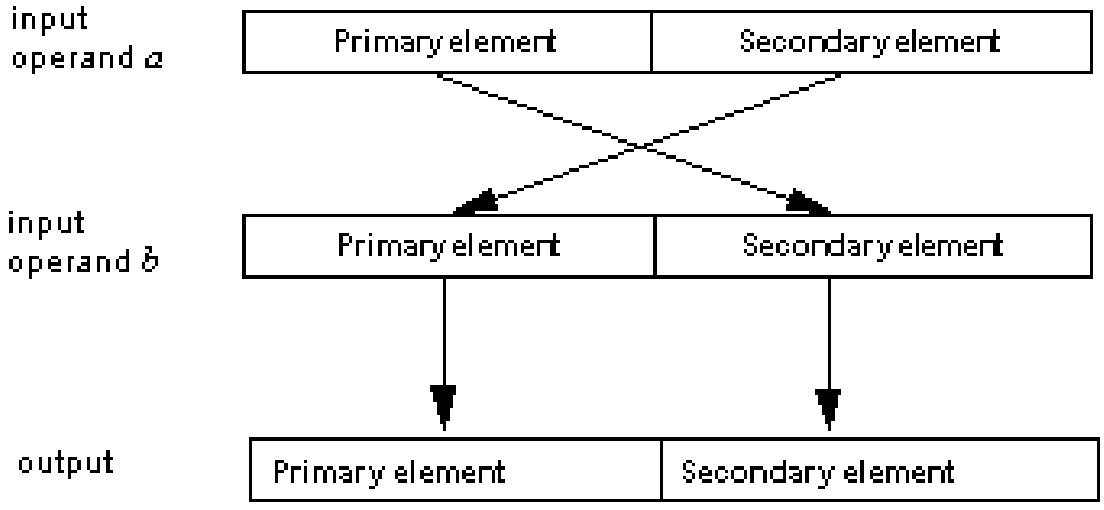



*Figure 9. Cross operations*

*Copy-primary* operations perform SIMD computation between the corresponding primary and secondary elements of two input operands, where the primary element of the first operand is replicated to the secondary element. As an example, Figure 10 on page 33 illustrates how a cross-primary multiply operation is performed.

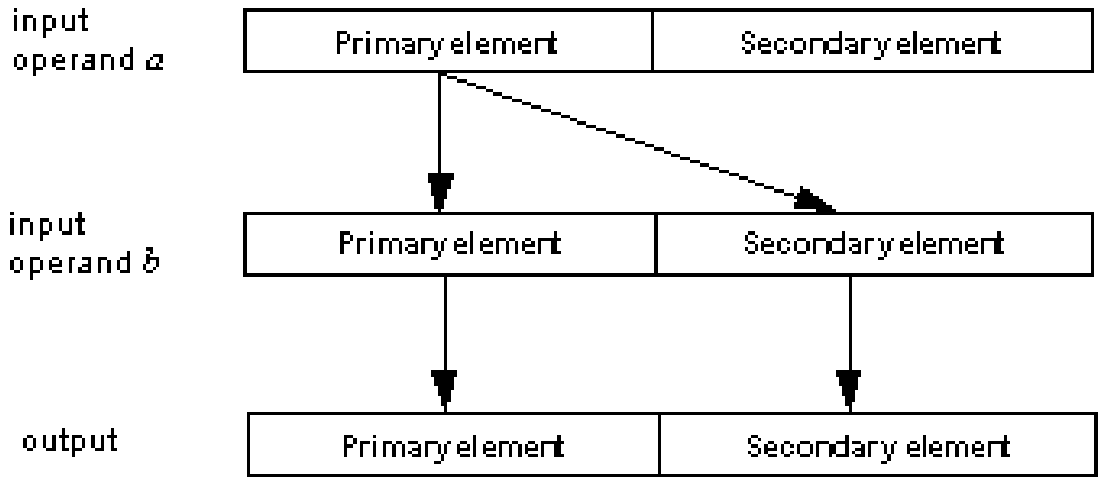



*Figure 10. Copy-primary operations*

*Copy-secondary* operations perform SIMD computation between the corresponding primary and secondary elements of two input operands, where the secondary element of the first operand is replicated to the primary element. As an example, Figure 11 illustrates how a cross-secondary multiply operation is performed.

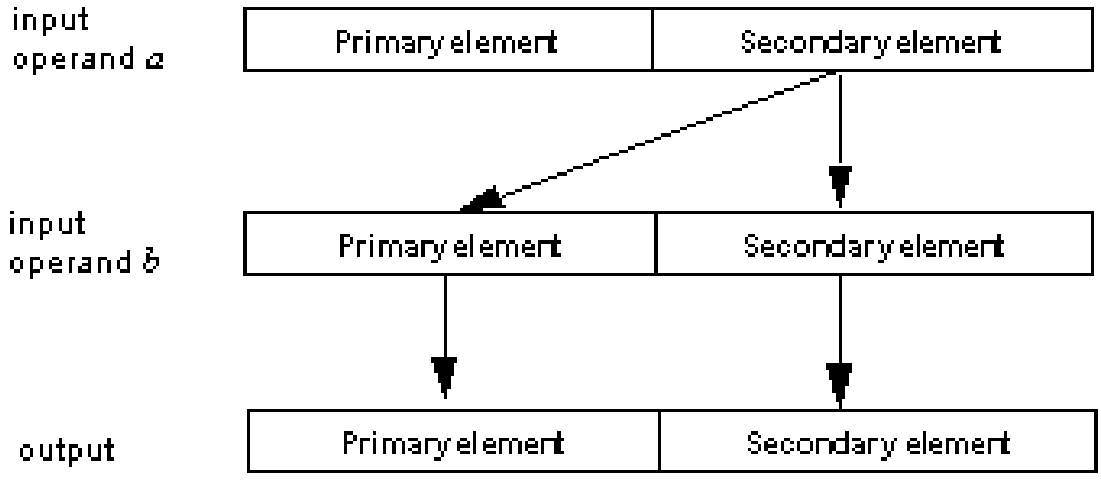



*Figure 11. Copy-secondary operations*

In *cross-copy* operations, the compiler crosses either the primary or secondary element of the first operand, so that copy-primary and copy-secondary operations can be used interchangeably to achieve the same result. The operation is performed on the total value of the first operand. As an example, Figure 12 on page 34 illustrates the result of a cross-copy multiply operation.

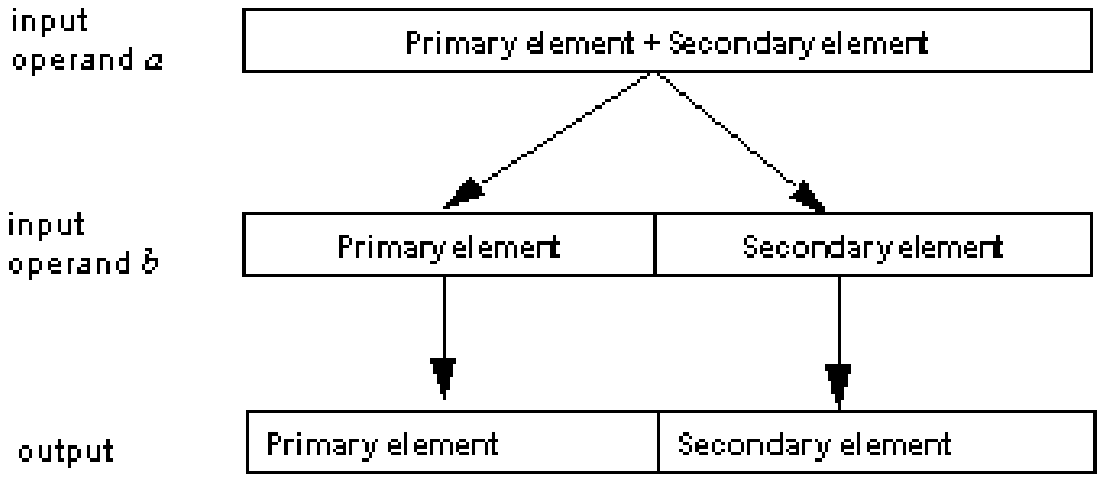



*Figure 12. Cross-copy operations*

The following sections describe the available built-in functions by category:

- Complex type manipulation functions
- Load and store functions
- Move functions
- Arithmetic functions
- Select functions

For each function, the C/C++ prototype is provided. In C, you do not need to include a header file to obtain the prototypes. The compiler includes them automatically. In C++, you need to include the header file `builtins.h`.

Fortran does not use prototypes for built-in functions. Therefore, the interfaces for the Fortran functions are provided in textual form. The function names omit the double underscore (__ ) in Fortran.

All of the built-in functions, with the exception of the complex type manipulation functions, require compilation under **-qarch=440d** for Blue Gene/L, or **-qarch=450d** for Blue Gene/P. This is the default setting for these processors.

To help clarify the English description of each function, the following notation is used:

*element* (*variable* )

where *element* represents one of *primary* or *secondary* , and *variable* represents input variable *a* , *b* , or *c* , and the output variable *result* . For example, consider the following formula:

```
primary(result) = primary(a) + primary(b)
```

The formula indicates that the primary element of input variable *a* is added to the primary element of input variable *b* and stored in the primary element of the *result*.

To optimize your calls to the Blue Gene built-in functions, follow the guidelines provided in Tuning your code for Blue Gene. Using the **alignx** built-in function (described in Checking for data alignment), and specifying the **disjoint** pragma (described in Removing possibilities for aliasing (C/C++)), are recommended for code that calls any of the built-in functions.

## Complex type manipulation functions

The functions described in this section are useful for efficiently manipulating complex data types, by allowing you to automatically convert real floating-point data to complex types, and to extract the real (primary) and imaginary (secondary) parts of complex values.

*Table 15. Complex type manipulation functions*

| **Function** | **Convert dual reals to complex (single-precision): __cmplxf** |
|---|---|
| Purpose | Converts two single-precision real values to a single complex value. The real *a* is converted to the primary element of the return value, and the real *b* is converted to the secondary element of the return value. |
| Formula | primary(result) = a<br>secondary(result) = b |
| C/C++ prototype | float _Complex __cmplxf (float a, float b); |
| Fortran description | CMPLX(A,B)<br><br>where A is of type REAL(4)<br>where B is of type REAL(4)<br>result is of type COMPLEX(4) |
| **Function** | **Convert dual reals to complex (double-precision): __cmplx** |
| Purpose | Converts two double-precision real values to a single complex value. The real *a* is converted to the primary element of the return value, and the real *b* is converted to the secondary element of the return value. |
| Formula | primary(result) = a<br>secondary(result) = b |
| C/C++ prototype | double _Complex __cmplx (double a, double b);<br>long double _Complex __cmplxl (long double a, long double b);[1] |
| Fortran description | CMPLX(A,B)<br><br>where A is of type REAL(8)<br>where B is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Extract real part of complex (single-precision): __crealf** |
| Purpose | Extracts the primary part of a single-precision complex value *a* , and returns the result as a single real value. |
| Formula | result = primary(a) |
| C/C++ prototype | float __crealf (float _Complex a); |
| Fortran description | N/A |
| **Function** | **Extract real part of complex (double-precision): __creal, __creall** |
| Purpose | Extracts the primary part of a double-precision complex value *a* , and returns the result as a single real value. |

*Table 15. Complex type manipulation functions (continued)*

| | |
|---|---|
| Formula | result = primary(a) |
| C/C++ prototype | double __creal (double _Complex a);<br>long double __creall (long double _Complex a);[1] |
| Fortran description | N/A |
| **Function** | **Extract imaginary part of complex (single-precision): __cimagf** |
| Purpose | Extracts the secondary part of a single-precision complex value *a* , and returns the result as a single real value. |
| Formula | result = secondary(a) |
| C/C++ prototype | float __cimagf (float _Complex a); |
| Fortran description | N/A |
| **Function** | Extract imaginary part of complex (double-precision): __cimag, __cimagl |
| Purpose | Extracts the imaginary part of a double-precision complex value *a* , and returns the result as a single real value. |
| Formula | result =secondary(a) |
| C/C++ prototype | double __cimag (double _Complex a); long double __cimagl (long double _Complex a);[1] |
| Fortran description | N/A |

**Notes:**

1. 128-bit C/C++ long double types are not supported on Blue Gene/L. Long doubles are treated as regular double-precision doubles.

## Load and store functions

Table 16 lists and explains the various parallel load and store functions that are available.

*Table 16. Load and store functions*

| **Function** | **Parallel load (single-precision): __lfps** |
|---|---|
| Purpose | Loads parallel single-precision values from the address of *a* , and converts the results to double-precision. The first word in *address(a)* is loaded into the primary element of the return value. The next word, at location *address(a)* +4, is loaded into the secondary element of the return value. |
| Formula | primary(result) = a[0]<br>secondary(result) = a[1] |
| C/C++ prototype | double _Complex __lfps (float * a); |
| Fortran description | LOADFP(A)<br><br>where A is of type REAL(4) or COMPLEX(4)<br>result is of type COMPLEX(8) |
| **Function** | **Cross load (single-precision): __lfxs** |

*Table 16. Load and store functions (continued)*

| | |
|---|---|
| Purpose | Loads single-precision values that have been converted to double-precision, from the address of *a*. The first word in *address(a)* is loaded into the secondary element of the return value. The next word, at location *address(a)* +4, is loaded into the primary element of the return value. |
| Formula | primary(result) = a[1]<br>secondary(result) = a[0] |
| C/C++ prototype | double _Complex __lfxs (float * a); |
| Fortran description | LOADFX(A)<br><br>where A is of type REAL(4) or COMPLEX(4)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel load: __lfpd** |
| Purpose | Loads in parallel values from the address of *a*. The first word in *address(a)* is loaded into the primary element of the return value. The next word, at location *address(a)* +8, is loaded into the secondary element of the return value. |
| Formula | primary(result) = a[0]<br>secondary(result) = a[1] |
| C/C++ prototype | double _Complex __lfpd(double* a); |
| Fortran description | LOADFP(A)<br><br>where A is of type REAL(8) or COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross load: __lfxd** |
| Purpose | Loads values from the address of *a*. The first word in *address(a)* is loaded into the secondary element of the return value. The next word, at location *address(a)* +8, is loaded into the primary element of the return value. |
| Formula | primary(result) = a[1]<br>secondary(result) = a[0] |
| C/C++ prototype | double _Complex __lfxd (double * a); |
| Fortran description | LOADFX(A)<br><br>where A is of type REAL(8) or COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel store (single-precision): __stfps** |
| Purpose | Stores in parallel double-precision values that have been converted to single-precision, into *address(b)*. The primary element of *a* is converted to single-precision and stored as the first word in *address(b)*. The secondary element of *a* is converted to single-precision and stored as the next word at location *address(b)* +4. |
| Formula | b[0] = primary(a)<br>b[1] = secondary(a) |
| C/C++ prototype | void __stfps (float * b, double _Complex a); |

*Table 16. Load and store functions (continued)*

| | |
|---|---|
| Fortran description | STOREFP(B,A)<br><br>where B is of type REAL(4) or COMPLEX(4)<br>where A is of type COMPLEX(8)<br>result is none |
| **Function** | **Cross store (single-precision): __stfxs** |
| Purpose | Stores double-precision values that have been converted to single-precision, into *address(b)*. The secondary element of *a* is converted to single-precision and stored as the first word in *address(b)*. The primary element of *a* is converted to single-precision and stored as the next word at location *address(b)* +4. |
| Formula | b[0] = secondary(a)<br>b[1] = primary(a) |
| C/C++ prototype | void __stfxs (float * b, double _Complex a); |
| Fortran description | STOREFX(B,A)<br><br>where B is of type REAL(4) or COMPLEX(4)<br>where A is of type COMPLEX(8)<br>result is none |
| **Function** | **Parallel store: __stfpd** |
| Purpose | Stores in parallel values into *address(b)*. The primary element of *a* is stored as the first double word in *address(b)*. The secondary element of *a* is stored as the next double word at location *address(b)* +8. |
| Formula | b[0] = primary(a)<br>b[1] = secondary(a) |
| C/C++ prototype | void __stfpd (double * b, double _Complex a); |
| Fortran description | STOREFP(B,A)<br><br>where B is of type REAL(8) or COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is none |
| **Function** | **Cross store: __stfxd** |
| Purpose | Stores values into *address(b)*. The secondary element of *a* is stored as the first double word in *address(b)*. The primary element of *a* is stored as the next double word at location *address(b)* +8. |
| Formula | b[0] = secondary(a)<br>b[1] = primary(a) |
| C/C++ prototype | void __stfxd (double * b, double _Complex a); |
| Fortran description | STOREFX(B,A)<br><br>where B is of type REAL(8) or COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is none |
| **Function** | **Parallel store as integer: __stfpiw** |

*Table 16. Load and store functions (continued)*

| | |
|---|---|
| Purpose | Stores in parallel floating-point double-precision values into *b* as integer words. The lower-order 32 bits of the primary element of *a* are stored as the first integer word in *address(b)*. The lower-order 32 bits of the secondary element of *a* are stored as the next integer word at location *address(b)* +4. This function is typically preceded by a call to the **__fpctiw** or **__fpctiwz** built-in functions, described in Unary functions, which perform parallel conversion of dual floating-point values to integers. |
| Formula | b[0] = primary(a)<br>b[1] = secondary(a) |
| C/C++ prototype | void __stfpiw (int * b, double _Complex a); |
| Fortran description | STOREFP(B,A)<br><br>where B is of type INTEGER(4)<br>where A is of type COMPLEX(8)<br>result is none |

## Move functions

*Table 17.*

| **Function** | **Cross move: __fxmr** |
|---|---|
| Purpose | Swaps the values of the primary and secondary elements of operand *a*. |
| Formula | primary(result) = secondary(a)<br>secondary(result) = primary(a) |
| C/C++ prototype | double _Complex __fxmr (double _Complex a); |
| Fortran description | FXMR(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |

## Arithmetic functions

The following sections describe all the arithmetic built-in functions, categorized by their number of operands:

- Unary functions
- Binary functions
- Multiply-add functions

### Unary functions

Unary functions operate on a single input operand. These functions are listed in Table 18.

*Table 18. Unary functions*

| **Function** | **Parallel convert to integer: __fpctiw** |
|---|---|

*Table 18. Unary functions (continued)*

| | |
|---|---|
| Purpose | Converts in parallel the primary and secondary elements of operand *a* to 32-bit integers. After a call to this function, use the **__stfpiw** function to store the converted integers in parallel, as described in Load and store functions. |
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fpctiw (double _Complex a); |
| Fortran description | FPCTIW(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel convert to integer and round to zero: __fpctiwz** |
| Purpose | Converts in parallel the primary and secondary elements of operand *a* to 32 bit integers and rounds the results to zero. After a call to this function, you will want to use the **__stfpiw** function to store the converted integers in parallel, as described in Load and store functions. |
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fpctiwz(double _Complex a); |
| Fortran description | FPCTIWZ(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel round double-precision to single-precision: __fprsp** |
| Purpose | Rounds in parallel the primary and secondary elements of double-precision operand *a* to single precision. |
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fprsp (double _Complex a); |
| Fortran description | FPRSP(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel reciprocal estimate: __fpre** |
| Purpose | Calculates in parallel double-precision estimates of the reciprocal of the primary and secondary elements of operand *a*. |
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fpre(double _Complex a); |
| Fortran description | FPRE(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel reciprocal square root: __fprsqrte** |
| Purpose | Calculates in parallel double-precision estimates of the reciprocals of the square roots of the primary and secondary elements of operand *a*. |

*Table 18. Unary functions (continued)*

| | |
|---|---|
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fprsqrte (double _Complex a); |
| Fortran description | FPRSQRTE(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel negate: __fpneg** |
| Purpose | Calculates in parallel the negative absolute values of the primary and secondary elements of operand *a*. |
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fpneg (double _Complex a); |
| Fortran description | FPNEG(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel absolute: __fpabs** |
| Purpose | Calculates in parallel the absolute values of the primary and secondary elements of operand *a*. |
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fpabs (double _Complex a); |
| Fortran description | FPABS(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel negate absolute: __fpnabs** |
| Purpose | Calculates in parallel the negative absolute values of the primary and secondary elements of operand *a*. |
| Formula | primary(result) = primary(a)<br>secondary(result) = secondary(a) |
| C/C++ prototype | double _Complex __fpnabs (double _Complex a); |
| Fortran description | FPNABS(A)<br><br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |

## Binary functions

Binary functions operate on two input operands. The functions are listed in Table 19.

*Table 19.*

| | |
|---|---|
| **Function** | **Parallel add: __fpadd** |

*Table 19. (continued)*

| | |
|---|---|
| Purpose | Adds in parallel the primary and secondary elements of operands *a* and *b*. |
| Formula | primary(result) = primary(a) + primary(b)<br>secondary(result) = secondary(a) + secondary(b) |
| C/C++ prototype | double _Complex __fpadd (double _Complex a, double _Complex b); |
| Fortran description | FPADD(A,B)<br><br>where A is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel subtract: __fpsub** |
| Purpose | Subtracts in parallel the primary and secondary elements of operand *b* from the corresponding primary and secondary elements of operand *a*. |
| Formula | primary(result) = primary(a) - primary(b)<br>secondary(result) = secondary(a) - secondary(b) |
| C/C++ prototype | double _Complex __fpsub (double _Complex a, double _Complex b); |
| Fortran description | FPSUB(A,B)<br><br>where A is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel multiply: __fpmul** |
| Purpose | Multiples in parallel the values of primary and secondary elements of operands *a* and *b*. |
| Formula | primary(result) = primary(a) × primary(b)<br>secondary(result) = secondary(a) × secondary(b) |
| C/C++ prototype | double _Complex __fpmul (double _Complex a, double _Complex b); |
| Fortran description | FPMUL(A,B)<br><br>where A is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | Cross multiply: __fxmul |
| Purpose | The product of the secondary element of *a* and the primary element of *b* is stored as the primary element of the return value. The product of the primary element of *a* and the secondary element of *b* is stored as the secondary element of the return value. |
| Formula | primary(result) = secondary(a) x primary(b)<br>secondary(result) = primary(a) × secondary(b) |
| C/C++ prototype | double _Complex __fxmul (double _Complex a, double _Complex b); |
| Fortran description | FXMUL(A,B)<br><br>where A is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross copy multiply: _fxpmul, __fxsmul** |

*Table 19. (continued)*

| | |
|---|---|
| Purpose | Both of these functions can be used to achieve the same result. The product of *a* and the primary element of *b* is stored as the primary element of the return value. The product of *a* and the secondary element of *b* is stored as the secondary element of the return value. |
| Formula | primary(result) = a x primary(b)<br>secondary(result) = a x secondary(b) |
| C/C++ prototype | double _Complex __fxpmul (double _Complex b, double a);<br>double _Complex __fxsmul (double _Complex b, double a); |
| Fortran description | FXPMUL(B,A) or FXSMUL(B,A)<br><br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |

## Multiply-add functions

Multiply-add functions take three input operands, multiply the first two, and add or subtract the third.

*Table 20.*

| **Function** | **Parallel multiply-add: __fpmadd** |
|---|---|
| Purpose | The sum of the product of the primary elements of *a* and *b*, added to the primary element of *c*, is stored as the primary element of the return value. The sum of the product of the secondary elements of *a* and *b*, added to the secondary element of *c*, is stored as the secondary element of the return value. |
| Formula | primary(result) = primary(a) × primary(b) + primary(c)<br>secondary(result) = secondary(a) × secondary(b) + secondary(c) |
| C/C++ prototype | double _Complex __fpmadd (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FPMADD(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel negative multiply-add: __fpnmadd** |
| Purpose | The sum of the product of the primary elements of *a* and *b*, added to the primary element of *c*, is negated and stored as the primary element of the return value. The sum of the product of the secondary elements of *a* and *b*, added to the secondary element of *c*, is negated and stored as the secondary element of the return value. |
| Formula | primary(result) = -(primary(a) × primary(b) + primary(c))<br>secondary(result) = -(secondary(a) × secondary(b) + secondary(c)) |
| C/C++ prototype | double _Complex __fpnmadd (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FPNMADD(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |

*Table 20. (continued)*

| **Function** | Parallel multiply-subtract: __fpmsub |
|---|---|
| Purpose | The difference of the primary element of *c*, subtracted from the product of the primary elements of *a* and *b*, is stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of the secondary elements of *a* and *b*, is stored as the secondary element of the return value. |
| Formula | primary(result) = primary(a) × primary(b) - primary(c)<br>secondary(result) = secondary(a) × secondary(b) - secondary(c) |
| C/C++ prototype | double _Complex __fpmsub (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FPMSUB(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Parallel negative multiply-subtract: __fpnmsub** |
| Purpose | The difference of the primary element of *c*, subtracted from the product of the primary elements of *a* and *b*, is negated and stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of the secondary elements of *a* and *b*, is negated and stored as the secondary element of the return value. |
| Formula | primary(result) = -(primary(a) × primary(b) - primary(c))<br>secondary(result) = -(secondary(a) × secondary(b) - secondary(c)) |
| C/C++ prototype | double _Complex __fpnmsub (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FPNMSUB(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross multiply-add: __fxmadd** |
| Purpose | The sum of the product of the primary element of *a* and the secondary element of *b*, added to the primary element of *c*, is stored as the primary element of the return value. The sum of the product of the secondary element of *a* and the primary element of *b*, added to the secondary element of *c*, is stored as the secondary element of the return value. |
| Formula | primary(result) = primary(a) × secondary(b) + primary(c)<br>secondary(result) = secondary(a) × primary(b) + secondary(c) |
| C/C++ prototype | double _Complex __fxmadd (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FXMADD(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross negative multiply-add: __fxnmadd** |

*Table 20. (continued)*

| | |
|---|---|
| Purpose | The sum of the product of the primary element of *a* and the secondary element of *b*, added to the primary element of *c*, is negated and stored as the primary element of the return value. The sum of the product of the secondary element of *a* and the primary element of *b*, added to the secondary element of *c*, is negated and stored as the secondary element of the return value. |
| Formula | primary(result) = -(primary(a) × secondary(b) + primary(c))<br>secondary(result) = -(secondary(a) × primary(b) + secondary(c)) |
| C/C++ prototype | double _Complex __fxnmadd (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FXNMADD(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross multiply-subtract: __fxmsub** |
| Purpose | The difference of the primary element of *c*, subtracted from the product of the primary element of *a* and the secondary element of *b*, is stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of the secondary element of *a* and the primary element of *b*, is stored as the secondary element of the return value. |
| Formula | primary(result) = primary(a) × secondary(b) - primary(c)<br>secondary(result) = secondary(a) × primary(b) - secondary(c) |
| C/C++ prototype | double _Complex __fxmsub (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FXMSUB(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross negative multiply-subtract: __fxnmsub** |
| Purpose | The difference of the primary element of *c*, subtracted from the product of the primary element of *a* and the secondary element of *b*, is negated and stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of the secondary element of *a* and the primary element of *b*, is negated and stored as the secondary element of the return value. |
| Formula | primary(result) = -(primary(a) × secondary(b) - primary(c))<br>secondary(result) = -(secondary(a) × primary(b) - secondary(c)) |
| C/C++ prototype | double _Complex __fxnmsub (double _Complex c, double _Complex b, double _Complex a); |
| Fortran description | FXNMSUB(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type COMPLEX(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross copy multiply-add: __fxcpmadd, __fxcsmadd** |

*Table 20. (continued)*

| | |
|---|---|
| Purpose | Both of these functions can be used to achieve the same result. The sum of the product of *a* and the primary element of *b*, added to the primary element of *c* , is stored as the primary element of the return value. The sum of the product of *a* and the secondary element of *b*, added to the secondary element of *c* , is stored as the secondary element of the return value. |
| Formula | primary(result) = a x primary(b) + primary(c)<br>secondary(result) = a x secondary(b) + secondary(c) |
| C/C++ prototype | double _Complex __fxcpmadd (double _Complex c, double _Complex b, double a);<br>double _Complex __fxcsmadd (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCPMADD(C,B,A) or FXCSMADD(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross copy negative multiply-add: __fxcpnmadd, __fxcsnmadd** |
| Purpose | Both of these functions can be used to achieve the same result. The difference of the primary element of *c*, subtracted from the product of *a* and the primary element of *b*, is negated and stored as the primary element of the return value. The difference of the secondary element of *c* , subtracted from the product of *a* and the secondary element of *b*, is negated stored as the secondary element of the return value. |
| Formula | primary(result) = -(a x primary(b) + primary(c))<br>secondary(result) = -(a x secondary(b) + secondary(c)) |
| C/C++ prototype | double _Complex __fxcpnmadd (double _Complex c, double _Complex b, double a);<br>double _Complex __fxcsnmadd (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCPNMADD(C,B,A) or FXCSNMADD(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross copy multiply-subtract: __fxcpmsub, __fxcsmsub** |
| Purpose | Both of these functions can be used to achieve the same result. The difference of the primary element of *c*, subtracted from the product of *a* and the primary element of *b*, is stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of *a* and the secondary element of *b*, is stored as the secondary element of the return value. |
| Formula | primary(result) = a x primary(b) - primary(c)<br>secondary(result) = a x secondary(b) - secondary(c) |
| C/C++ prototype | double _Complex __fxcpmsub (double _Complex c, double _Complex b, double a);<br>double _Complex __fxcsmsub (double _Complex c, double _Complex b, double a); |

*Table 20. (continued)*

| | |
|---|---|
| Fortran description | FXCPMSUB(C,B,A) or FXCSMSUB(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross copy negative multiply-subtract: __fxcpnmsub, __fxcsnmsub** |
| Purpose | Both of these functions can be used to achieve the same result. The difference of the primary element of *c*, subtracted from the product of *a* and the primary element of *b*, is negated and stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of *a* and the secondary element of *b*, is negated stored as the secondary element of the return value. |
| Formula | primary(result) = -(a x primary(b) - primary(c))<br>secondary(result) = -(a x secondary(b) - secondary(c)) |
| C/C++ prototype | double _Complex __fxcpnmsub (double _Complex c, double _Complex b, double a);<br>double _Complex __fxcsnmsub (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCPNMSUB(C,B,A) or FXCSNMSUB(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross copy sub-primary multiply-add: __fxcpnpma, __fxcsnpma** |
| Purpose | Both of these functions can be used to achieve the same result. The difference of the primary element of *c*, subtracted from the product of *a* and the primary element of *b*, is negated and stored as the primary element of the return value. The sum of the product of *a* and the secondary element of *b*, added to the secondary element of *c*, is stored as the secondary element of the return value. |
| Formula | primary(result) = -(a x primary(b) - primary(c))<br>secondary(result) = a x secondary(b) + secondary(c) |
| C/C++ prototype | double _Complex __fxcpnpma (double _Complex c, double _Complex b, double a);<br>double _Complex __fxcsnpma (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCPNPMA(C,B,A) or FXCSNPMA(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross copy sub-secondary multiply-add: __fxcpnsma, __fxcsnsma** |
| Purpose | Both of these functions can be used to achieve the same result. The sum of the product of *a* and the primary element of *b*, added to the primary element of *c*, is stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of *a* and the secondary element of *b*, is negated and stored as the secondary element of the return value. |
| Formula | primary(result) = a x primary(b) + primary(c))<br>secondary(result) = -(a x secondary(b) - secondary(c)) |

*Table 20. (continued)*

| | |
|---|---|
| C/C++ prototype | double _Complex ____fxcpnsma (double _Complex c, double _Complex b, double a);<br>double _Complex __fxcsnsma (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCPNSMA(C,B,A) or FXCSNSMA(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross mixed multiply-add: __fxcxma** |
| Purpose | The sum of the product of *a* and the secondary element of *b*, added to the primary element of *c*, is stored as the primary element of the return value. The sum of the product of *a* and the primary element of *b*, added to the secondary element of *c*, is stored as the secondary element of the return value. |
| Formula | primary(result) = a x secondary(b) + primary(c)<br>secondary(result) = a x primary(b) +secondary(c) |
| C/C++ prototype | double _Complex __fxcxma (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCXMA(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross mixed negative multiply-subtract: __fxcxnms** |
| Purpose | The difference of the primary element of *c*, subtracted from the product of *a* and the secondary element of *b*, is negated and stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of *a* and the primary element of *b*, is negated and stored as the primary secondary of the return value. |
| Formula | primary(result) = -(a × secondary(b) - primary(c))<br>secondary(result) = -(a × primary(b) - secondary(c)) |
| C/C++ prototype | double _Complex __fxcxnms (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCXNMS(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross mixed negative sub-primary multiply-add: __fxcxnpma** |
| Purpose | The difference of the primary element of *c*, subtracted from the product of the secondary element of *a* and the secondary element of *b*, is negated and stored as the primary element of the return value. The sum of the product of *a* and the primary element of *b*, added to the secondary element of *c*, is stored as the secondary element of the return value. |
| Formula | primary(result) = -(secondary(a) × secondary(b) - primary(c))<br>secondary(result) = a × primary(b) + secondary(c) |

*Table 20. (continued)*

| | |
|---|---|
| C/C++ prototype | double _Complex __fxcxnpma (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCXNPMA(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |
| **Function** | **Cross mixed sub-secondary multiply-add: __fxcxnsma** |
| Purpose | The sum of the product of *a* and the secondary element of *b*, added to the primary element of *c*, is stored as the primary element of the return value. The difference of the secondary element of *c*, subtracted from the product of *a* and the primary element of *b*, is stored as the secondary element of the return value. |
| Formula | primary(result) = a x secondary(b) + primary(c))<br>secondary(result) = -(a x primary(b) - secondary(c)) |
| C/C++ prototype | double _Complex __fxcxnsma (double _Complex c, double _Complex b, double a); |
| Fortran description | FXCXNSMA(C,B,A)<br><br>where C is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where A is of type REAL(8)<br>result is of type COMPLEX(8) |

## Select functions

Table 21 lists and explains the select functions that are available.

*Table 21. Select functions*

| **Function** | **Parallel select: __fpsel** |
|---|---|
| Purpose | The value of the primary element of *a* is compared to zero. If its value is equal to or greater than zero, the primary element of *c* is stored in the primary element of the return value. Otherwise, the primary element of *b* is stored in the primary element of the return value. The value of the secondary element of *a* is compared to zero. If its value is equal to or greater than zero, the secondary element of *c* is stored in the secondary element of the return value. Otherwise, the secondary element of *b* is stored in the secondary element of the return value. |
| Formula | primary(result) = if primary(a) ≥ 0 then primary(c); else primary(b)<br>secondary(result) = if secondary(a) ≥ 0 then primary(c); else secondary(b) |
| C/C++ prototype | double _Complex __fpsel (double _Complex a, double _Complex b, double _Complex c); |
| Fortran description | FPSEL(A,B,C)<br><br>where A is of type COMPLEX(8)<br>where B is of type COMPLEX(8)<br>where C is of type COMPLEX(8)<br>result is of type COMPLEX(8) |

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